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A Simulation Study of Instrument Meteorological Condition Approaches to Dual Parallel Runways Spaced 3400 and 2500 Feet Apart Using Flight-Deck-Centered Technology

Marvin C. Waller and Charles H. Scanlon
Langley Research Center, Hampton, Virginia

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

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ABSTRACT

A number of our nation's airports depend on closely spaced parallel runway operations to handle their normal traffic throughput when weather conditions are favorable. For safety these operations are curtailed in Instrument Meteorological Conditions (IMC) when the ceiling or visibility deteriorates and operations in many cases are limited to the equivalent of a single runway. Where parallel runway spacing is less than 2500 feet, capacity loss in IMC is on the order of 50 percent for these runways. Clearly, these capacity losses result in landing delays, inconveniences to the public, increased operational cost to the airlines, and general interruption of commerce.

This document presents a description and the results of a fixed-base simulation study to evaluate an initial concept that includes a set of procedures for conducting safe flight in closely spaced parallel runway operations in IMC. Consideration of flight-deck information technology and displays to support the procedures is also included in the discussions. The procedures and supporting technology rely heavily on airborne capabilities operating in conjunction with the air traffic control system.

Introduction

A number of our nation's airports depend on closely spaced parallel runway operations to handle their normal traffic throughput when weather conditions are favorable. For safety these operations are curtailed in Instrument Meteorological Conditions (IMC) when the ceiling or visibility deteriorates, and operations in many cases are limited to the equivalent of a single runway. Where parallel runway spacing is less than 2500 feet, capacity loss due to IMC is on the order of 50 percent. Even in the dependent operations environment, where typically parallel runways are spaced between 2500 feet and 4300 feet, capacity loss is frequently on the order of 25 percent. Clearly these capacity losses result in landing delays causing inconveniences to the traveling public, interruptions in commerce and increased operating cost to the airlines.

Airborne Information for Lateral Spacing (AILS) is a research and development activity aimed at finding a solution to this lost capacity problem by applying flight-deck-centered technology. This work is a part of the Reduced Spacing Operations (RSO) Subelement of the NASA Terminal Area Productivity (TAP) Project. NASA Langley sponsored a workshop in the fall of 1996 that reviewed work related to this research and development activity (ref. 1). An overview of the study and results described in this document was presented at that workshop, and the slides used are reproduced in reference 1.

In the years preceding the AILS research and development, the Federal Aviation Administration (FAA) made progress on the problem of lost parallel runway capacity in IMC through its Precision Runway Monitoring (PRM) Program (ref. 2). Using ground-based technology consisting primarily of more accurate radar and higher resolution displays for Air Traffic Control (ATC) stations, that program has certified a system and procedures to operate independent parallel approaches as close as 3400 feet in IMC.

Reference 3 documents the results of a NASA Langley contracted study of parallel runway operations. The effort included development of a Monte Carlo model of parallel runway operations that facilitates parametric analyses of the effectiveness of avoiding near-miss incidents and collisions when one aircraft deviates from its nominal path into the airspace of adjacent parallel traffic. The study reported in reference 3 also used the model that was developed to analyze parameters influencing close parallel runway operations and execution of safe escape maneuvers when an intrusion incident transpires. That study and further application of the model at NASA Langley were instrumental in developing the concept under investigation in the subject study.

This document presents a description and the results of a fixed-base simulation study to evaluate an initial concept that includes a set of procedures for conducting safe flight in the closely spaced parallel runway operations in IMC, as well as information technology and displays to support those procedures. These procedures and the supporting technology rely heavily on airborne capabilities operating in conjunction with the ATC system.

List of Acronyms and Abbreviations

ADS-B	Automatic Dependent Surveillance Broadcast: A position-reporting and limited data-communication system under development for aviation applications
AILS	Airborne Information for Lateral Spacing
ANOVA	Analysis of Variance
ATC	Air Traffic Control
CRT	Cathode Ray Tube
CDU	Control Display Unit
DF	Degrees of Freedom, parameter used in ANOVA
DGPS	Differential GPS
dsply	Abbreviation for “display,” used in an ANOVA table
F	F-test statistic used in ANOVA
FAF	Final Approach Fix
GPS	Global Positioning System: A U.S. Government owned space based navigation system available for general purpose applications including aviation
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MS	Mean Square, used in ANOVA, equals the SS divided by DF

MOTAS	Mission Oriented Terminal Area Simulator, an ATC and air traffic simulation facility located at NASA Langley
NASA	The National Aeronautics and Space Administration
ND	Navigation Display
NM	Nautical Miles
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
PRM	Precision Runway Monitor
R&D	Research and Development
RA	TCAS Resolution Advisory
RSO	Reduced Spacing Operations
SAE	Society of Automotive Engineering
scn	Abbreviation for scenario used in an ANOVA table
s.d.	Standard deviation
spd	Abbreviation for speed used in an ANOVA table
spc	Abbreviation for runway spacing used in an ANOVA table
SS	Sum of Squares, used in ANOVA
TA	TCAS Traffic Advisory
TAP	Terminal Area Productivity (Project)
TCAS	Traffic Alert and Collision Avoidance System: An airborne collision-avoidance system currently in use in the airspace system and required for commercial passenger transports
TOGA	Take Off and Go Around
TSRV	Transport Systems Research Vehicle
VMC	Visual Meteorological Conditions

The Concept

The basic concept under study is illustrated in figure 1. A pair of parallel approaches is under consideration since that case is simpler than the triplet or quadruplet cases and does represent a costly real world problem in itself. It is expected that the solution of the simpler two runway problem will lead to solutions in the more complex cases. Figure 1 shows two airplanes on closely spaced parallel approaches in IMC under the concept. Each aircraft is equipped with an accurate navigation system such as Differential Global Position System (DGPS) navigation, an Automatic Dependent Surveillance Broadcast (ADS-B) communication link to transmit or broadcast its own state and other information for use by other airplanes and ground facilities. Each airplane also receives the ADS-B information from the other airplanes operating within its proximity and on the adjacent approach. The airplanes are also equipped with a traffic display, possibly similar to the TCAS displays currently in use, but upgraded with monitoring and warnings specific to the parallel runway concept requirements. In this concept, the primary responsibility for maintaining separation from traffic operating on the parallel approach is shifted from the Air Traffic Control (ATC) facility to the flight deck of the airplanes. From a separation-responsibility standpoint, this operation is similar to ATC oversight as with current Visual Meteorological Condition (VMC) approaches to closely spaced parallel runways (visual approaches). However, separation from other traffic, such as that behind and ahead operating in the same approach stream, may be maintained as the responsibility of the ground-based ATC operation.

This basic concept for conducting closely spaced parallel approaches in IMC can be partitioned into two primary aspects: (1) accurate navigation required to keep each aircraft in their own airspace, and (2) an alerting and escape process to ensure safety in the event of an intrusion where one airplane leaves its nominal approach path and threatens the safety of an airplane on the adjacent parallel approach path. As a guideline, the display concepts were designed to adhere as closely as reasonable to TCAS formats with deviations only where they appear to provide added value in supporting the parallel approach requirements. Furthermore, in initial experimental implementations of the concept, the flight deck display of information is presented as modifications to the Primary Flight Display (PFD) and the Navigation Display (ND) since these are the display devices that normally occupy the majority of pilots' attention during the approach phase of flight. Figure 2 shows the unmodified versions of these instruments as they appear in the fixed-base NASA Transport System Research Vehicle (TSRV) Simulator used.

The concept for presenting alerts in the flight deck was intended to adhere to the requirements of SAE ARP4102/4 and its recommendations for level two and level three alerting (ref. 4). In that industry standard, level two alerting requires presenting visual and aural information to the operator signaling the alert condition using amber colors in the display. A level two alert does not require a corrective action, although in some applications corrective action is appropriate. The level three alerting status requires presenting visual and aural alerting information to the operator and has the color red associated with its display. A level three alert requires that the operator takes a corrective action.

Required Tracking

The first of the two aspects of the flight-deck-centered parallel approach concept is to provide accurate navigation to keep aircraft in their airspace along the approach paths. The concept incorporates boundaries for an acceptable lateral deviation from the extended runway centerline that are generally much closer to the runway centerline than boundaries defined by conventional two-dot ILS localizer deviation. Using DGPS and controlling within the reduced boundaries reduces the potential for path overlap. NASA is currently exploring use of the modified localizer path guidance illustrated in figure 3. In the area of localizer capture the two dot deviation is 2000 feet on either side of the extended runway centerline. Also, as is normal for parallel runway operations, the two parallel approach paths are separated vertically by a minimum of 1000 feet during localizer capture. Approximately 12 NM from the runway threshold, the two-dot localizer path widths begin to taper down to 500 feet on either side of the extended runway centerline at 10 NM. After the 500-foot half-width area is entered, the higher aircraft starts to descend, reducing the altitude separation. The 500-foot half width of the path is held from that point to the middle marker, where the angular shape and width of the conventional localizer beam are recaptured.

For the AILS concept, the localizer deviation pointer sensitivity will be adjusted by airborne algorithms so that a two-dot deviation represents the AILS localizer boundary profile as shown in figure 3. The DGPS navigation capability is assumed to provide the accurate navigation to support the lateral path navigation along the entire approach. It is recognized that other technologies may also be capable of providing the required level of navigation accuracy. The Required Navigation Performance (RNP) is 0.04 NM.

An own-ship alerting feature has also been incorporated in the concept to prevent aircraft from straying from their assigned airspace. Should an airplane deviate one dot or more from its nominal path (but less than two dots), a level two alert is issued to the deviating aircraft with displayed information presented in amber alphanumeric and symbolic formats in the PFD and in the ND, to warn the flight deck crew to maintain a tighter path adherence. The PFD and ND in their nominal configuration during an AILS approach where no alert has been activated are shown in figure 4. A display of the traffic on the parallel approach has been added to the ND using TCAS symbol formats. Figure 5 shows an example of the PFD and ND with a level two (caution) alert indicating an abnormal deviation of the own ship from its nominal path. In the example shown in figure 5, the deviation is approximately one and one quarter dots. Adhering to the SAE standard, the localizer scale and pointer, the own-ship symbol in the ND, and the “LOCALIZER” alphanumeric symbol flashing near the center of the PFD are displayed in amber. The display formats are discussed in more detail in a later section.

If an airplane deviates two dots or more from its localizer centerline, a level three alert is issued on its flight deck displays. Figure 6 illustrates the display of a level three alert presented in the flight deck of the aircraft deviating from its nominal path two dots or more. Again, the features of the display will be described in more detail in a later section of this document. The level three alert requires immediate corrective action by the flight crew. In the example of figure 6, the flashing “TURN CLIMB” alphanumeric display, the localizer scale and pointer in the PFD, and the own airplane symbol in the ND are displayed in red, indicating the requirement for a break-off maneuver in the direction away from the parallel traffic.

The current AILS experimental concept requires use of a single identical break-off maneuver for all parallel approach level three alerts. The aircraft is required to break off the approach by executing an emergency turning, climbing maneuver to a heading 45° away from the nominal runway heading in the direction away from the parallel approach path traffic. The flight crew must then contact ATC for further instructions. In the current experimental implementation, a heading bug in the ND (see fig. 6) is automatically set to the escape heading when the alerting algorithms are armed. Executing the break-off maneuver is mandatory on receiving the two dot deviation alert; no recovery attempt is permitted. This requirement for a mandatory break off may be relaxed in follow-up versions of the concept, pending further examination.

Alerting and Escape Maneuver for an Intrusion

The second aspect of the AILS experimental parallel approach concept addresses procedures and flight-deck information presented to aid in avoiding collisions and near misses in the event that the parallel traffic strays from its airspace and approaches the path of the own ship in a threatening manner. An onboard alerting algorithm, to be discussed later, uses state information from the traffic nominally on the parallel approach, transmitted by ADS-B, for example, to detect threatening aircraft and provide an onboard alert to the flight-deck crew of the threatened aircraft. Again, the alert is presented in the PFD and the ND. A level two caution is presented in amber when the onboard alerting system detects the threat as it starts to evolve. Figure 7 presents an example of the flight deck displays as such a level two alert is issued. The word “TRAFFIC” is displayed in the central area of the PFD in amber. In the ND the traffic symbol for the parallel airplane changes to an amber-filled circle according to TCAS conventions. According to SAE standards, the flight crew is not required to take corrective action.

As the danger becomes more imminent based on the computations associated with the alerting algorithms, a level three alert is issued. Figure 8 illustrates the display features presented as an intruding aircraft sets off the level three alert. Also, a computer-controlled voice message would be presented when a level three alert is given: “Turn, climb. Turn, climb. Turn, climb.” A level three alert caused by intruder traffic requires the flight crew to break off the approach. The same maneuver is required as when the own ship could not stay within its two dot lateral path boundary. This maneuver would be depicted on the approach plate and is different than the missed approach procedure.

Intrusion Alerting Algorithms

The initial work to develop the intrusion alerting algorithms used in this study was completed in a contracted study documented in reference 5. An alternative alerting algorithm was completed in a separate contracted study and is reported in reference 6. Primarily because of the higher level of maturity of the algorithm presented in reference 5 at the time that this study was initiated, that alerting algorithm, with some modifications to its details, was implemented in this experimental concept. This algorithm is referred to as the segmented alerting algorithm and is described in detail in reference 5 along with steps completed to validate it.

Figure 9 presents a summary of the features of the modified segmented alerting algorithm. Based on the bank angle, track angle, and ground speed of the intruder airplane, the time and position of its crossing the nominal path of the own ship is estimated. The parameters D and TAU are set by the user. The protected distance about the own ship is D and TAU is a time parameter specified in seconds. The distance of the traffic airplane from the own ship at the projected path crossing is computed based on the state information of the two airplanes, assuming that the intruder continues on its current track. Next, other potential ground tracks are considered. These are tangent to the projected turn arc in the range of 5° to 35° from the runway heading (starting at the current track angle). If any path crossing distance is determined to be less than D, the corresponding time (t_alert) of the intruder arriving at the distance D from the own ship is estimated.

Alerts are initiated if

$$\text{t\_alert} \leq \text{TAU} \quad \text{and} \quad \text{projected\_range\_at\_path\_crossing} \leq \text{D}\ .$$

The segmented alerting algorithms were implemented in two stages, a level-two caution and a level-three warning. Threshold alert times and distances were selected for the level two and level three alerts. These were established empirically based on test operations in the simulator prior to the experiment. Table 1 presents the values used in the study.

Table 1. Time and Distance Threshold Parameters Used in the Alerting Algorithms.

Alert Type	Threshold Time, TAU	Threshold Distance, D
Caution (level two)	30 sec	2000 ft
Warning (level three)	15.5 sec	1000 ft

The Experiment Design

The purpose of this experiment was to evaluate, in simulation, the effectiveness of a concept for conducting parallel approach operations. This concept consists of two parts: (1) maintaining airplanes in their own airspace and (2) avoiding an intruder aircraft by at least 500 feet should an intrusion incident occur. The experiment was designed to evaluate the effects of the following parameters on the process:

1. Two different runway spacing environments—3400 and 2500 feet

2. Two different display formats

3. Two different intruder speeds, the intruder airplane being 30 knots faster or 30 knots slower than the own ship

4. Different intruder paths or encounter geometries.

The modified localizer path width, described earlier, was used throughout this experiment. The own-ship lateral path deviations from the extended runway centerline were monitored during the approach operations to verify that the pilot could fly within the ±500-foot two dot path boundary.

The test matrix used is shown in the following table:

Table 2. Test Matrix

Display Formats
- Modified Conventional
- Enhanced

Runway Spacings
- 3400 ft
- 2500 ft

Intruder Speeds
- Intruder 30 knots faster
- Intruder 30 knots slower

Test Scenarios
- Five with 30° intruder heading
- One with no intruder incident
- One with intruder breakoff

A complete factorial design was used with 16 test subjects, all of whom were current line pilots. One of two pilot confederates (in-house pilots who were not test subjects) acted as the pilot not flying

(PNF) with each of the test subjects who was the pilot flying (PF) in the experiment. Each of the two pilot confederates participated as PNF with eight of the test subjects.

Display Formats

For this study, AILS parallel approach information was displayed in the PFD and ND. The study assumes implementation in a glass flight deck aircraft, with an expectation that similar methods potentially can be derived for implementation in electromechanical flight decks. Two display formats were evaluated with differences occurring only in the ND. The two display formats are referred to as (1) the Modified Conventional Display, which used the 10 NM range scale in the navigation display and (2) the Enhanced Display, which used a specially added 2 NM range scale in the ND. Examples of the two display formats are shown in figure 10 in a nominal approach condition with no alerts activated. There were some other differences in the details that will be discussed later.

In the ND of both formats (see fig. 10) an escape heading bug is set at the heading on the compass rose at the AILS procedural 45° escape heading in the direction away from the parallel traffic and runway. This bug is set automatically when the AILS algorithms are activated before the airplanes start their descent, giving up their 1000-foot altitude separation. The AILS alerting algorithms are activated at the point at which the airplanes enter the narrow linear 500-foot wide portion of the localizer path (see fig. 3), 10 NM from the runway threshold.

Besides the scale change between the Modified Conventional Display and the Enhanced Display, the own-ship symbol size was different. As shown in figure 10, for the Enhanced Display, the symbol for the own ship is reduced in size and a 500-foot radius, scaled circle encloses the arrow-head shaped aircraft symbol. The 500-foot circle represents the protected space around the own ship for avoiding a near miss. In the case of the 10 NM range scaling of the Modified Conventional Display format, the 500-foot radius circle would be too small to be a meaningful display symbol, therefore it is not presented.

Own-Ship Tracking:

Figure 11 presents an example of each of the two display formats when a level two alert (caution) is presented to inform the pilots of their own ship straying from its assigned airspace, with more than one dot but less than two dot localizer deviation. As previously discussed, the color amber or yellow is associated with a level two alert according to industry display standards (Ref. 4). In both display formats, the word "LOCALIZER" is displayed in the center portion of the PFD in amber. The own-ship symbol is changed from white to amber in the navigation display of both display formats. Also, the localizer scale in each display format is changed from its original white color to amber to assist the pilots in recognizing the nature of the problem causing the level two alert condition.

Figure 12 presents an example of each of the two display formats when a level three (warning) alert is presented to inform the pilots of their own ship straying from its assigned airspace with two dots or more localizer deviation. This alerting condition requires immediate corrective action, i.e., the pilots must execute an immediate, accelerating, climbing turn away from the direction of the parallel traffic. The color red is used in displaying information related to a level three alert condition. In both display formats the alphanumeric symbols "TURN, CLIMB" are displayed in the central area of the PFD. In the navigation display the own-ship symbol is changed from its nominal white color to red (after having been displayed in amber in the level two alert condition). Both formats include an aural announcement "Turn, climb" repeated three times.

Intruder Alerting:

Figure 13 presents the two display formats with a level two alert in the case of the parallel traffic having been determined to pose a collision or near-miss threat according to the intrusion alerting algorithms. In each case an alphanumeric display of the word “TRAFFIC” is presented in the central portion of the PFD in amber. The parallel traffic symbol is shown in the ND deviating from its nominal path and colored amber. The Enhanced Display format has an added feature facilitated by its increased magnification—a display of the predicted relative path of the intruder airplane. This display feature presents the predicted path of the intruder airplane relative to the predicted path of the own airplane. The prediction algorithm includes the assumption that the two airplanes will maintain their current attitudes and speeds. The predicted relative path is displayed as a sequence of dots projected in 2-second intervals. The intent of this display symbol is to allow the pilots, with a quick glance of the ND, to understand the nature of the threat. It is emphasized that this display symbol is relative path and not ground track information. The magnification in the Modified Conventional Display (10 NM range) would not allow resolution of the features of such a relative path presentation; therefore, no such feature was presented in that display format.

Figure 14 shows the two display formats with a level three traffic alert condition requiring immediate corrective action. The “TURN CLIMB” red alphanumeric symbols are presented in the central portion of the PFD similar to the level three condition for excessive localizer deviation. Both formats include an aural announcement “Turn, climb” repeated three times. In the ND, the color of the traffic symbol and its information tag is changed from the amber of the level two condition to red. As a display enhancement in the Enhanced Display format, a red arrow-head triangular symbol is used as the traffic symbol to allow orientation of the traffic symbol to the heading of the intruding traffic. The presentation of the relative path information is continued in the level three alert presentation and its color is also changed from amber to red. During escape maneuvering, the relative path display could be used by the pilots to determine the effectiveness of the maneuvers they executed.

Runway Spacing

Two levels of spacing between runways were used in this study. The first was 3400 feet which was selected to match the minimum runway spacing certified for current PRM operations. It was desired that the test would substantiate that the flight-deck centered process would result in safety and performance that was comparable with the PRM system certification at 3400 feet runway spacing.

The second runway spacing selected was 2500 feet, with the rationale that success at this spacing would offer potential for a substantial but conservative incremental improvement over currently available technology. Based on earlier analysis and exploratory simulator operations, it was felt that there was a high probability of success with this spacing.

Intruder Speeds

The two intruder airspeeds selected for use in the study were 30 knots incremental to the nominal speed of 140 knots of the own ship. One level was 110 knots for a slower intruder and the second was 170 knots for a faster intruder.

Test Scenarios or Paths of the Intruder Airplane

Seven scenarios were used in the tests. These are illustrated in figure 15. The first of the seven traffic airplane paths (1) was a normal flight profile with no unusual excursions from the localizer centerline. The second path (2) was intended to simulate a profile where the parallel traffic airplane would have initially made a lateral deviation from the nominal path toward the path of the own airplane. It was assumed that the parallel traffic then received a level three turn climb break-off command from its own tracking alerting algorithms. In that scenario, the potential intruder initiated a turning climb maneuver in the direction away from the threatened airplane. In the other five paths, the intruder made excursions in the direction of the own ship at 30° angles from its nominal track. Path three (3) was designed to have the intruder pass 1500 feet ahead of the own ship if the own ship continued at its nominal 140 knots with no turns. It was intended to generate a level two alert but not a level three. Path four (4) was designed to result in a 500-foot pass ahead (with no evasive maneuver) and generate a level three alert. Path five (5) was designed to result in a direct hit (with no evasive maneuver) and generate a level three alert. Path six (6) was designed to present a nominal 500-foot pass behind the own ship and generate a level three alert. Path seven (7) was designed to result in a nominal 1500-foot pass behind the own ship and nominally generate a level two alert but not a level three alert. In summary, with the selected parameters of the alerting algorithms, paths 2, 3, 4, 5, 6, and 7 were planned to introduce a level two alert in the simulated flight deck. Only paths 4, 5, and 6 were designed to initiate a level three alert.

The Test Facility

The test was conducted on the NASA Transport System Research Vehicle Simulator (fig. 16). This facility is a fixed-base simulator of a generic glass flight deck. The dynamics of the simulated airplane represented a Boeing 737-100 transport airplane. The control system used was an augmented manual mode, attitude control wheel steering implemented with a side stick mount for left hand operation by the pilot in the left flight-deck seat, who was the subject of the experiment. Other flight controls typical of a transport airplane were operational, including a console mounted throttle control, a flap control, a control display unit (CDU), a mode control panel, a landing gear lever, rudder pedals, multiple radio control heads, and microphones for radio communication.

The flights were conducted using a generic terminal area model with runways 26L and 26R having even thresholds. A crosswind of 10 knots from 170° or 350° was used in all runs, selected such that it was in the direction of the intruder. Light turbulence was also included.

An oculometer for measuring operator look point was used to measure and record the eye scanning behavior of the pilots. Reference 7 includes a discussion of this equipment and the techniques used for analyzing the data.

Experimental Procedure

This section describes the procedure used to conduct the simulation experiment. It includes a discussion of the briefing given to the pilots and training prior to the experiment. It also presents a description of how the scenarios were generated and implemented in the experiment.

Pilot Briefing and Training

Each pilot was tested during a 2-day period. Training sessions were conducted on each day prior to the testing sessions. The intent was to train the subjects to proficiency in accordance with normal airline procedures. The training on the first day consisted of a 1-hour presimulator briefing plus 50 minutes of simulator training. Two retired airline captains were used as training instructors. Each instructor trained one-half of the subjects following a training script to ensure that the subjects would receive uniform training. The same instructor also served as the pilot not flying during data collection runs.

The 1-hour presimulator briefing began with a discussion by the experimenter describing the parallel runway study activity including a statement of the problem, a brief description of the AILS concept as a proposed solution and the facilities to be used in the study. Next, the instructor pilot discussed the role of the subject pilot in the experiment, features of the AILS procedures from the flight-deck perspective, the various safety alerts incorporated into the AILS algorithm from the piloting perspective, the simulated airport and approach procedures, the TSRV simulator, pilot-flying (PF) and pilot-not-flying (PNF) responsibilities, and the specific crew procedures that were to be used during the experiment. The subjects were told that the same single response was always required when a level three intruder alert was received. That response was to initiate an immediate, climbing, accelerating turn away from the traffic to a heading of 45° from the nominal runway heading using a 30° bank angle.

The 50-minute simulator training session began with a description of the controls and switches of the TSRV simulator. The subject was briefed on those features of the display and control system that were different from the conventional technology in the field, information presented in the flight deck that is specifically related to the parallel runway operations, the experiment, and the flight plan and charts used in the experiment.

Three types of training runs were then accomplished to familiarize each subject with AILS procedures in the TSRV simulator. The first runs reinforced the normal AILS approach procedures that had been previously discussed during the briefing. These runs were also used by the instructor to highlight features of the simulator and displays. No alerts were introduced during these runs. The second runs highlighted air work and allowed the subject to practice several “turn-and-climb” maneuvers. The instructor observed the air work and provided feedback on numerous items including the proper positioning of hands on the throttles, feet on the rudders, use of the side stick controller, reaction time, and roll, pitch, and yaw control. The third run types allowed the subject to practice the AILS procedure with sample test cases including level three traffic alerts and allowed the instructor to determine if the subject had been successfully trained to proficiency. In some cases the instructor and subject were satisfied after one practice/evaluation run. Typically, not more than three were used.

The proficiency training was ended when, in the judgment of the instructor, the subject demonstrated the correct AILS procedures and completed the escape maneuvers with a miss-distance of at least 1200 feet with appropriate proficiency. Also the subject was asked if he or she was comfortable with the procedure. According to the instructors, who had significant airline training experience as instructors, this evaluation criterion is consistent with airline training for similar time critical maneuvers such as a rejected takeoff (RTO), emergency depressurization, engine out on takeoff, and engine-out missed approach. Once the subjects reached end-level-proficiency, no additional training or coaching was provided and no training or coaching was provided during the data runs.

To aid the instructor in analyzing the subject’s technique, the miss-distance, reaction time, and mean EEM rate-of-roll were calculated for the evaluation runs and displayed on an unused portion of the engine indicator and caution and alerting system (EICAS) display at the end of the runs. Generally, the subjects became aware of this information and its significance during the training sessions. This training information was not available in the flight deck after the training session was completed.

According to the instructor pilots who acted as consultants in designing the AILS procedures, airline pilots are typically trained to mentally review time-critical maneuvers before the time of execution. Therefore, this technique was incorporated into the AILS training. Each subject was instructed to review the steps to be taken to accomplish an EEM during the final approach briefing and again mentally whenever an amber “traffic” caution was observed in the display.

Only one of the two display formats was used on a particular day with a given subject. The pilots were trained with the particular display format that was to be used during the testing of that day. Training time was provided at the start of the second day for operations with the second display format. The second day’s training required approximately 20 minutes in the simulator including the instructor’s explanation of the second display format and the subject flying one or two practice runs. Eight of the sixteen subjects were tested with the Modified Conventional format first and the other eight were tested with the enhanced format first to avoid confounding display format effects with order of testing or learning effects.

Intruder Profiles

The intruder path profiles were prerecorded in digital files. These files were based on the simulated flights flown in a manual mode in the same atmospheric conditions used in the tests—light turbulence and a 10-knot crosswind. Prerecorded flights were made with the intruder track deviation prescribed by each of the seven scenarios of the test. The data in the files were manually manipulated to accomplish the requirements for each data run. This was completed during the experiment setup period, prior to the start of all testing. A more detailed discussion of how the prerecorded tracks were generated is presented in appendix A.

The test runs were started with the own airplane on one of the two approach paths with a heading to intersect the localizer at a 30° angle. The traffic airplane was initiated for an approach on the parallel approach path. Figure 17 presents an illustration of a plan view of a sample path of the two simulated airplanes during an approach in which there was an intrusion. The intrusion angle was always 30°. The initial altitude separation of the paths was 1000 feet, with one approach nominally at 8400 feet and the other at 7400 feet. The TSRV simulator was initialized at 8400 feet altitude during one half of the data runs for a given pilot, and at 7400 feet for the other half. This was a factor included in randomizing the order of test conditions to prevent the subjects from guessing the scenarios as they were presented.

Results

This section describes the results of the simulation experiment, including both objective and subjective measures. The analyses of miss distance and pilot reaction time include only the scenarios that would have resulted in a collision or near miss if the pilots did not execute an escape maneuver. There were three such scenarios included in the tests, scenarios 4, 5, and 6 (see fig. 15). Therefore, the size of the experiment included in the analysis of variance was 384 tests trials (2 runway spacing levels $\times$ 2 displays $\times$ 2 intruder speeds $\times$ 3 scenarios $\times$ 16 pilots). The test design was a complete factorial design with no replications. By the nature of the design, the pilot effect was implicitly confounded with the replications. This meant that pilot effects could not be distinguished from repeats of the same condition. Therefore, no attempt will be made to analyze pilot differences. This is the normal protocol for this type of experimental design. In analyzing this experiment, 0.05 or lower value of the significance of F will be accepted as indicating a statistically significant difference.

Miss Distance

The miss distance is a key parameter in this study. Earlier studies (ref. 4) in certifying the PRM system for 3400-foot runway spacing operations established 500 feet (assumed to mean center of mass to center of mass) as the minimal miss distance, below which a near miss incident will have occurred during an intruder incident. Thus for this experiment, 500 feet or less clearance at the closest approach would be taken to mean that the AILS process did not prevent an unacceptable situation. For clear acceptability it would be expected that miss distances would be significantly in excess of this minimum to assure that conclusions of the present study would be conservative. An Analysis of Variance (ANOVA) of the miss distances measured in this study is presented in table 3. The miss distances presented are three-dimensional slant range at the closest approach point.

Display Effects

Based on the analysis of variance (table 3), effects of the two formats of the display were not a significant factor in determining the miss distances in this study. The performance of the pilots with the Modified Conventional Display using the 10 NM range format in the ND was approximately the same as with the Enhanced Display with the 2 NM range. There is also no evidence that the presentation of the predicted path information in the ND benefited the miss distance performance. Figure 18 presents mean miss distance versus display format and runway spacing. The mean miss distance for the 2 NM range display is 1939 feet with a standard deviation of 258 feet. The mean for the 10 NM display range is 1953 feet with a standard deviation of 274 feet. As the data included in figure 18 indicates, the miss distance performance with each of the display formats was about the same within each runway separation.

Runway Spacing Effects

In the ANOVA presented in table 3, runway spacing is shown to have had a significant effect on the miss distance performance. This may seem to be an obvious result; however, the design of the alerting criterion tends to dampen this effect by attempting to wait until a geometrically similar threatening situation to activate the alert for each runway spacing. Figure 19 presents the effects of runway separation on the miss distance. The mean miss distance for the 3400-foot runway spacing is 1968 feet with a standard deviation of 250 feet. The mean miss distance for the 2500-foot runway spacing is 1924 feet with a standard deviation of 280 feet. The mean for the more distant runway spacing is 44 feet greater. Although statistically significant, it is not clear that this difference has very much operational significance. The closest approach overall in the test was 1183 feet in the 2500-foot runway spacing case. This result supports the premise that the alerting algorithms tend to present alerts at similar geometric configurations regardless of the runway spacing. The pilot performance was also approximately the same at the different runway spacings, as will be shown in the analysis of response time presented in a later section .

Relative Speed Effects

Relative speed of the intruder airplane was also found to have a significant effect on the miss distance (table 3). Figure 20 presents mean and standard deviation data for the effects of relative speed on miss distance. The closest encounters were measured for the conditions in which the intruder was slower than the own airplane; however, the difference is only 150 feet. Figure 21 presents the mean deviations of the intruder airplane from its approach runway extended centerline at the time the alert was activated. It shows that the intruder was farther displaced from its own runway centerline when the alert was sounded for the slower intruder cases, and therefore closer to the parallel traffic approach path, by an average of approximately 600 feet.

Table 3. ANOVA of the Miss Distance Measurements

Source of Variation	SS	DF	MS	F	Significance of F
display (dsply)	44354.50	1	44354.50	1.47	.226
spacing (spc)	428067.82	1	428067.82	14.19	.000
speed (spd)	3086506.07	1	3086506.07	102.3	.000
scenario (scn)	7209434.60	2	3604717.3	119.5	.000
display × spacing	56187.57	1	56187.57	1.86	.173
display × speed	6995.63	1	6995.63	.23	.630
display × scenario	5669.66	2	2834.83	.09	.910
spacing × speed	208367.25	1	208367.25	6.91	.009
spacing × scenario	95662.91	2	47831.46	1.59	.206
speed × scenario	7968264.83	2	3984132.2	132.1	.000
dsply × spc × spd	3595.38	1	3595.38	.12	.73
dsply × spc × scn	1462.04	2	731.02	.02	.97
dsply × spd × scn	18120.38	2	9060.19	.30	.74
spc × spd × scn	492388.94	2	246194.47	8.16	.000
dsply × spc × spd × scn	31868.63	2	15934.32	.53	.59
Model	19656945.75	23	854649.82	28.34	.000
Residual	10858362.31	360	3162.12		
Total	30515308.06	383	79674.43		

Scenario Effects

The scenario or intruder path was found to have a significant effect on the miss distances measured (table 3). Figure 22 presents additional data describing the effect of the different intruder paths on the miss distance. Included are the results for the 500-foot pass ahead (should no escape maneuver be executed), the center-of-gravity to center-of-gravity collision, and the 500-foot intruder pass behind the simulated TSRV airplane cases. The mean miss distances for the collision cases and the 500-foot pass ahead cases are close in value at 2059 feet and 2032 feet, respectively. The value measured for the pass behind case (1747 feet) was approximately 300 feet less than the other two cases, indicating that this was the worst in terms of miss distance.

Figure 23 shows the separation of the intruder airplane from the own ship when the level three alert was initiated. Each of the six scenario and speed combinations is presented separately. The case in which the intruder airplane was slow and set up to pass behind the own ship was the closest to the own ship when the level three alert was initiated. Figure 24 shows a plot of the mean separation of the two airplanes versus time from the alert. A plot for each of the six scenario and speed combinations is included. One quarter second time increments were used. Each point on the plots averages 64 separation distances (16 subjects × 2 runway spacings × 2 displays). These plots show that, in the case of the 500-foot slow intruder passing behind, the intruder is closer when the alert is presented and remains closer over the period of the evasion maneuver, at least up to point of closest approach. The alerting algorithms include consideration of the proximity of the slow intruder approaching from behind. It evaluates that case as posing a less time-critical threat than the other cases tested. Therefore, it allows these threat cases to approach closer than it does the other cases tested before initiating an alert.

Several interaction effects were shown to be significant in the ANOVA presented in table 3. Included in these was the two-way interaction of speed and scenario. This interaction was essentially discussed in the explanation of the scenario effect above and the related results are shown in figure 22, which shows that, in the intruder passing behind case, the slow speed of the intruder resulted in a closer approach than the other cases. The source of the significance of the other interaction effects does not appear to be quite so clear. Figure 25 presents closest approach versus runway spacing and relative speed and figure 26 presents closest approach versus runway spacing, relative speed, and scenario.

When measured from the time of the level three alert, the intruder's progress in the 30° turns was different for the 3400- and the 2500-foot cases. More of the turning path of the intruder was included in the evaluation of the 2500-foot case than in the 3400-foot case. This implies that the relative paths of the intruder were actually different between the two runway spacing values, but this is realistic in terms of the physics of the situations. Also, the ground speed (and subsequently the airspeed) of the intruder is a factor in the turning arc and therefore influences the time before the rollout occurred to capture the 30° relative cross track.

Pilot Reaction Time

Pilot reaction time was measured as the time from the start of the level three alert until the pilot input of a half-stick roll attitude control deflection or until the autothrottle disconnect button was pressed. The bench mark response time for the break off procedure was 2.0 seconds as is used in airline procedures for a rejected takeoff. An ANOVA of the response time measurements was conducted; however, none of the independent variables were determined to have significant effects on the reaction time. The mean reaction time for all test conditions was 0.71 second with a standard deviation of 0.22 second. Figure 27 presents the reaction time versus runway spacing and display format.

Tracking Performance

The data were analyzed to determine the amount of time each flight exceeded one dot and two dot localizer deviation. This analysis was made only when the aircraft was within the 500-foot two-dot localizer width section of the approach and when no red alert had been initiated. The analysis included all data runs. One subject exceeded the one dot boundary during three different runs for periods of 8.5, 6.5, and 9.25 seconds, respectively. There were no other excursions by any pilot outside of the 250-foot one dot width. The total flight time included in the evaluation was 40.71 hours. The portion of the run time inside the $\pm$250-foot band was 99.98 percent.

Pilots' Use of the Displays Based on Scanning Behavior

The oculometer data, recording pilot look point, was reduced by dividing the display area into six rectangular regions (see fig. 28) that captured the primary flight display (PFD), the navigation display (ND), the front window, the mode control panel (MCP), and the engine status and miscellaneous information (Misc. Info). The engine status and miscellaneous information CRT's were initially included in the analysis but were removed because no data were measured in those areas. Previous studies have shown that most of the attention of the pilot flying is focused in the PFD and ND during the approach phase of flight. The focus of this discussion is therefore on these two areas in the following analysis.

This analysis addresses only the runs during which there was an intruder warning (red alert) initiated. Each simulated flight was analyzed first as an entire run with all data included from the start of the run until it was terminated. Next, each flight was divided into the following six sequential parts or segments for additional analysis:

1. Segment 1 was from the start of the run to localizer capture.

2. Segment 2 was from the localizer capture to glideslope capture in the vicinity of the outer marker.

3. Segment 3 was from glideslope capture until 15 seconds prior to the intruder warning, red alert.

4. Segment 4 was from 15 seconds before the red alert until the end of the run.

5. Segment 5 is included in segment 4 and was from 15 seconds prior to the alert until the red intruder warning alert was presented. It includes the caution alert period.

6. Segment 6 includes the period from the red alert until the run ended, and is also included in segment 4.

The primary parameter selected to describe the pilots' use of the displays is the percentage of the look point dwell (dwell percentage) on the PFD and the ND. The dwells (sometimes referred to as dwell times in experimental psychology literature) are time periods during which the pilot's look point is determined to be stable (not in transition within an instrument or between instruments). The following definitions are assumed and are consistent with software vendor-supplied descriptions although not necessarily consistent with some of the existing operator scanning behavior literature. A "dwell" is defined as the time period in seconds during which a fixation or series of contiguous fixations remain within an area of interest. A fixation is a (pilot's or other human subject's) viewing event characterized by the x,y-look point coordinates measured by the oculometer remaining within a 1° by 1° area during a 0.10-second period or longer. This contrasts with a saccade, during which the eyes are concluded to be in motion from one fixation point to another, when no information is assumed to be absorbed by the subject. In effect, the dwell percentage for a data collection period represents the total percentage of time the pilot was viewing the information presented in the particular area of interest, such as on the PFD. It is normalized based on the total time the pilot was determined to be visually "fixating" on any location during the period under examination (e.g., test run). If a mean dwell percentage of 85 percent was determined for the PFD, that means that out of all of the time the subject was measured to be looking at locations (all dwells), 85 percent of the time was determined to be viewing the PFD. In general, the data presented in the following discussion are pooled over all subjects of the simulation tests.

Over the set of data analyzed, dwells in the PFD and the ND account for approximately 90 percent of all total viewing time recorded. One-and-one-half percent of the dwell time was determined to be out of the front window viewing. Approximately 8 percent of the other locations were at points not recognized by the data analysis scheme.

Figure 29 presents a summary of the dwell percentages of the pilots' viewing over the set of entire runs separated for the two display formats, the Modified Conventional Display and the Enhanced Display. The dwell percentages on the ND show that there was more use of the ND when the higher magnification display (2 NM, Enhanced Display) was used. The dwell percentage when the Modified Conventional Display was used is 5.4 percent and when the Enhanced Display was used it was 6.4 percent. Although there is only a small difference in the magnitude of the increase of about 1 percent *(where percentage is the normalized unit of the measurement)*, the difference was found to be highly significant at better than the .001 level in the analyses of variance presented in table 4. The increase is (1.0/5.4 × 100 =) 18.5 percent *(referring to proportions and not the unit of the measurement)*. One might be inclined to think that the 1-percentage point measured increase is not of physical significance; however, this is a statistically significant measurement that relates to the pilots' evaluation of the Enhanced Display as being more desirable.

Table 4. Analysis of Variance of ND Dwell Percentages

ANOVA					
Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (Type I error Probability)*
Display	1484.3	1	1484.3	24.5	.000
Segment	4322.8	5	864.6	14.3	.000
Display × Segment	448.0	5	89.6	1.42	.193
Residual	126988.2	2100	60.5		
Total	252500.5	2112			

*Values of .05 or less are interpreted as statistically significant.

The results presented in table 4 show that the display format was found to be a statistically significant effect, and the run segment was significant. This finding indicates that in the different segments of the simulated flight some differences in amount of viewing of the ND were measured and that it would possibly be informative to look at the segment differences to better understand the effects of the display formats on the dwell percentage.

In terms of physical units the difference is small, a change of 1 percent of all of the look point dwells. Yet, further analysis indicates the difference is caused by a high percentage of viewing of the Enhanced Display in the periods during the emergency condition when the intruder alerts were in effect.

Figure 30 presents dwell percentage data broken down in terms of segments of the approach and includes data for both display formats combined. It is evident that there is relatively high use of the ND in segment 1 during localizer capture as would be expected. Use of the ND is relatively low in segments 2 and 3, as also would be expected considering that there are only minimal navigational tasks for the flight crews in this portion of the flight. Lateral displacement from the extended runway centerline in the form of localizer deviation information is included in the PFD. However, during the period of time associated with the intrusion incident, captured in segments 4, 5 and 6 (segment 4 includes segments 5 and 6), use of the ND is at its highest levels. This shows that the ND, which includes the display of the parallel traffic, is used an increased amount by the pilot flying during the period in which the intrusion incident is in progress.

Figure 31 presents dwell percentage data for the flights using the Modified Conventional Display. This figure shows that the trends in using the ND along the approach segments are the same as for the combined results of the 10 NM and 2 NM ND; however, the amounts of utilization in segments 4 (Alert-15), 5 (Alert-15->End), and 6 (Alert->End) are less than the corresponding means for the combined data set (fig. 30). This observation clearly shows that the utilization of the ND in these segments is higher in the flights where the 2 NM range Enhanced Display (that also presents the predicted relative path information) was used. Figure 32 presents the dwell percentage data for the flights where the Enhanced Display format was used. In segment 4, the segment in which the intrusion incidents occurred, the dwell time when using the ND was 10 percent with the Enhanced Display format compared to 7 percent with the Modified Conventional Display format. Based on dwell percentage measurements, it is concluded that during the process of managing an intrusion incident, the 2 NM range ND was used (3/7 × 100 =) 43 percent more than the 10 NM format. It is emphasized that the scaling of the Enhanced Display was not the only format difference. In particular, the relative path information presented may have been as important an influence as the increased scale factor.

In summary, the dwell percentage data show that the 2 NM enhanced navigation display was used more than the 10 NM format. This supports the claims of the pilots in their evaluations of the display formats that the 2 NM format was more useful during the intrusion incidents. There were also measured statistically significant increases in use of the ND during the segments of the flight during which the intrusion incident occurred compared to the straight-in final approach segments preceding the intrusion incidents.

To some degree, variation in the pilots' use of the PFD reflected the inverse of the changes observed for the ND. Figures 29 through 32 show that there is most often a decrease in the dwell percentage on the PFD when there is an increase in the dwell percentage on the ND. In the analysis of variance results of the PFD dwell percentage (table 5), the display and the segment were both significant. The discussion above focused on the ND from the vantage point that changes in the PFD usage probably resulted from shifts of viewing from the PFD to the ND. It was also noted that during the alert period, particularly as an evasive maneuver was in progress, the pilot's head was in motion as different locations in the flight deck were viewed and control levers manipulated. The head motion resulted in significantly more loss of look point data than the portions of the flights where more normal operations were in progress. Therefore, the proportion of the pilot look point data that could be successfully analyzed was lower in those segments.

Table 5. Analysis of Variance of PFD Dwell Percentages

ANOVA					
Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance (Type I error Probability)*
Display	5065.2	1	5065.2	14	.000
Segment	231146.5	5	46229.3	128	.000
Display × Segment	1820.5	5	364.1	1	.411
Residual	758055.9	2100	361.0		
Total	995978.8	2112			

*Values of .05 or less are interpreted as statistically significant

Pilot Evaluation

The pilots were given a debriefing questionnaire at the end of the testing of each display and runway combination. There were four debriefing sessions for each pilot since there were two runway spacings and two display formats. The other independent variables of the test were distributed and balanced within the four sets of runway spacing and display format groups. The final debriefing session included two additional forms on which the pilots were asked to evaluate miscellaneous aspects of the experiments.

Appendix B provides a copy of the forms used and a compilation of the responses of the subject pilots. The data presented also include the comments made by each subject on the forms. The following subsections present a summary of the responses made by the pilots in a narrative format.

Display of Parallel Traffic

The subjects were asked about the extent of their use of the traffic display in the ND. Their answers reflected a general view that during the localizer capture phase of the flights they used it a significant amount. Most replies ranged from “occasionally” to “frequently,” although some subjects marked the “never” and “rarely” choices. When asked a similar question about the straight-in portion of the approach, the choices made were even more clustered in the “occasionally” to “frequently” range.

The subjects were asked about the usefulness of the traffic display in the ND. When the Enhanced Display was used, they generally replied that this display was helpful, most often selecting “somewhat helpful” or “quite helpful” as their choice. Two subjects chose the “essential” selection. When the Modified Conventional Display was evaluated, the majority of the replies were also “somewhat helpful” or “quite helpful.” However, a number of the subjects selected the “of little help” choice for this display format. This is the only item on the questionnaire for which the ANOVA analysis of the replies, discussed in a later section, showed a significant difference. The difference was between the two display formats.

The subjects were asked about the workload in using the two display formats. They generally replied that the additional workload associated with using the display formats was “moderate” to “low.”

Use of the Out-of-the-Window View

The subjects were asked about their out-of-the-window viewing, since it was possible that the intruder could be seen out of the window in some situations. The visibility in the fog scene was specified as 1/4 NM. They were asked about their out-of-the-window viewing in attempting to see the traffic during each of four phases of the flights: the localizer capture, the straight-in portion of the approach, the period during the evasive maneuver, and the period after the evasive maneuver. The replies were about the same for each. Most were distributed between “never” and “rarely." A few “occasionally” responses were given and one subject responded “frequently” for the period after the evasive maneuver.

Alerts

The subjects were asked if the time available after the level three alert was given was adequate to maneuver safely. The choices were: inadequate, somewhat inadequate, about right, somewhat excessive, and highly excessive. Most of the subjects chose “about right." Two or three, depending on which of the display and runway combinations, chose “somewhat excessive.”

When asked about the alphanumeric “TURN, CLIMB” presented near the center of the PFD, their selected responses ranged from “somewhat helpful” to “absolutely essential,” with the largest number of replies being “very helpful” or “absolutely essential.” When asked about the computer voice alert “Turn, climb! Turn, climb! Turn, climb!” the replies were similar to those given for the alphanumeric presentation of the alert, with somewhat fewer responses in the “absolutely essential” choice. The “very helpful” choice was favored instead.

Traffic Path Information in the ND

For the case of the Enhanced Display, the subjects generally indicated that they did not look at or rarely looked at the predicted path information prior to initiating a maneuver when the level three alert was given. Two subjects did indicate that they looked “occasionally” or “frequently.”

The subjects were asked if acquiring information on the probable path of the intruder was important in avoiding a collision. Their choices were: never, rarely, occasionally, frequently, and always. Their replies were distributed fairly evenly over the range of choices when the Enhanced Display format was used, and clustered more around the “never” and “rarely” choices when the Modified Conventional Display format was used.

The subjects were asked whether the relative path information aided in a decision to maneuver. The relative path information could be viewed after the level two caution alert was given, prior to the level three alert, as well as during the level three alert. Half of the subjects chose “never.” The other responses were generally distributed between “rarely” and “frequently.” They were asked whether the predicted path information aided them in determining what maneuver to make. The replies were fairly evenly distributed over the range “never” to “always.”

The replies to the similar question about the traffic information when the Modified Conventional Display was used showed a stronger bias toward the choices indicating that the information was not used or not helpful in making decisions about the escape maneuver, although a few replies indicated occasional help.

Summary of the Subjects’ Comments

The following statements summarize the results of the debriefing with an attempt to highlight the most important points. However, since some discretion was necessary in developing a summary and all comments are not reflected in the list below, review of the specific comments made by each subject (appendix B) will provide the reader with a better understanding of the comments made.

1. The consensus of pilot opinion was that this definitely is a realistic process and an excellent start.

2. The pilots generally preferred the 2 NM display capability.

3. They felt that the task can be accomplished adequately with the 10 NM map scale range.

4. They recommended displaying escape heading information and also providing information indicating that the AILS alerting algorithms were “armed” in the PFD.

5. They felt that the pilot flying would use the ND display in a minimal manner, while a pilot not flying would pay heavy attention to the traffic display.

6. They recommended providing escape guidance in the PFD. Specifically they recommended keeping the flight director command bars active during the escape maneuver to provide the desired guidance.

7. They recommended making AILS an autopilot coupled approach procedure.

8. They stated that the 45° degree heading comes up too quickly in the "violent" maneuver called for in the procedures and using a turn to 90° or at least something significantly more than the 45° heading would be better.

9. Several pilots commented that they would have broken off with an airplane crossing in front of them as in the 1500 foot ahead intruder pass where no break-off or level three alert was presented.

10. Some concern was expressed that the single escape maneuver was not always appropriate. Some pilots felt that breaking to the side of the approaching traffic was occasionally appropriate. For example, if the traffic is approaching from the right rear, it might be more feasible to break to the right.

11. Concern was raised by one pilot that the intruder might try to correct back to the nominal path. In this case, the display elements might not accommodate the off nominal behavior of the unpredictable situation.

    (Note: Pilot 2, q.17: There could be a situation when the intruder has passed in front or behind, therefore changing sides. Then if he decides to get back on course, he could intrude again from the other side, causing your escape bug to be invalid.)

12. The pilots felt that the 2 NM display range in the ND gives good situation awareness during an intrusion. The wide field of view, 10 NM display range does not.

13. One subject suggested that the pilot flying could have a wide field of view while the pilot not flying uses the high resolution small field of view. The pilot not flying would then relay information to the pilot flying.

14. One pilot suggested including a marking showing when a red alert will be issued on the relative path display in the ND.

15. One subject suggested keeping aircraft on the same frequency for improved situation awareness.

16. Several pilots commented that the lag between the visual "Turn climb" in PFD and the aural "Turn, climb, ..." was disturbing and that it should be avoided. (The visual information appeared first.)

17. One pilot commented that the 10 NM ND display was not very useful and distracted the pilot's attention from the PFD when he was trying to gain situation information from the low resolution presentation.

18. One pilot commented that the "expanded mode was too expanded– traffic off of the screen pops up and becomes a factor too quickly."

19. Several pilots recommended the addition of turn direction to the alert displays. Visual: Left turn, climb. Aural: Left turn, climb … etc.

20. One pilot commented that a trend vector (predicted path information) on the intruder in the Modified Conventional Display format would be helpful.

21. One pilot commented that flight ID information on the traffic added to the clutter and provided no useful information.

ANOVA of the Questionnaire Data

Analyses of variance were completed on the responses given by the pilots on the debriefing questionnaire. The dependent variables were the subject response selections made on the debriefing forms. Each response was given a numeric value 1, 2, 3, 4, or 5 according to the order of the response on the form. The responses were ordered to be qualitatively descending or ascending on the questionnaire form. The responses compared in a given ANOVA were the same set of choices in response to the same question.

For example, one question was:

1. During the localizer capture, I looked at the adjacent-traffic display in the ND

a. never b. rarely c. occasionally d. frequently e. continually

If the response was "a," it was converted to 1 in the analysis. A response of "b" was converted to 2, "c" to 3, "d" to 4, and "e" to 5. This question was presented for the Enhanced Display with each of the two runway spacing levels. It was also presented for the Modified Conventional Display combined with each runway spacing. Once the qualitative data were converted to quantitative data, a conventional ANOVA was completed for that question. The independent variables were the two levels of display format, and the two runway spacing levels.

Table 6. ANOVA of Response to the Question Rating the Value of the Display Formats.

ANOVA					
Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Significance
Display	11.39	1	11.39	22.73	.000
Spacing	.14	1	.14	.28	.598
Display × Spacing	.39	1	.39	.78	.381
Residual	30.06	60	.50		
Total	819.00	64			

There was only one question that resulted in statistically significantly different responses at the .05 significance level or better. This was question number three (3) on the questionnaire form:

Overall, I found the navigation display of traffic in this mode

a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

The results of the ANOVA for this question are presented in table 6 where only the "Display" factor is shown to be significant.

Conclusions

An initial simulation study of a concept for flight-deck-centered approaches to parallel runways in IMC has been completed. The concept includes flight-deck-centered technology and procedures to assist the pilots in maintaining flight in their assigned airspace and to assure safety in the event of an intrusion where one airplane threatens to cross into the airspace of another.

This study included two values of runway spacing (3400 feet and 2500 feet), two display conditions, two intruder airplane speeds, and three intruder paths across the approach path of the own ship that were collision threats. Four intruder scenarios that were not collision threats were also included. Sixteen airline pilots participated as test subjects.

Mean miss distance during intruder incidents and pilot reaction time were the measurements of highest interest in this study. For the level-three-alert intrusion cases, the mean miss distance recorded was 1946 feet (s.d. 266 feet) and the mean pilot reaction time was 0.71 second (s.d. 0.22 second). Variations in display conditions did not produce a statistically significant difference in the miss distance or pilot reaction time. However, most of the pilots commented that they preferred the Enhanced Display that included the higher magnification scale factor in the ND and a display of the relative path of the intruder. Their comments indicated that with a quick glance they could discern the necessary situation information with the 2 NM range-scaled ND of the Enhanced Display. However, they commented that that was not the case with the 10 NM, lower magnification ND in the Modified Conventional Display which also did not include the specially designed display of relative path of the intruding airplane. The analysis of variance of the questionnaire responses to the question addressing the usefulness of information in the ND supported the conclusion that the pilots preferred the Enhanced Display format.

The pilots commented that the proposed procedures and displays for conducting the parallel runway approaches were highly acceptable to them. They commented that they could adequately perform the required procedures for either approach spacing and with either display format. They did make a number of specific recommendations for improving the displays. These included bringing the display of the escape turn direction into the PFD and providing escape maneuver guidance in the PFD, in particular, through the flight director command bars. They also commented that a coupled approach is more likely to be certified and recommended that the AILS process should be investigated in such an implementation.

The effects on miss distance of the relative speed of the intruder, runway spacing (3400 or 2500 feet) and the conflict geometry were found to be statistically significant factors; however, their effects were minimized by the performance of the alerting algorithms. None of the independent variables of the test resulted in statistically significant differences in pilot reaction times.

In terms of path tracking performance, 99.98 percent of the recorded measurements were within the ±250-foot one-dot localizer width defined for this concept. Only one pilot deviated beyond that lateral path width during the flights.

It is concluded that the AILS process for conducting parallel runway operations in IMC is promising and that particular issues should be addressed to make the process suitable for application in the field. The issues include:

1. This study has shown that a set of procedures and displays is sufficient; however, all information provided may not be necessary. The cost of implementing each aspect of the technology must be

considered in a practical system. This issue is also important in considering retrofitting older-technology, electromechanical flight decks.

2. Does the process work equally well in an autopilot coupled approach?

3. The issues of disconnecting from the autopilot and executing the break-off maneuver should be studied in a variety of certified aircraft simulators.

4. What is the role of ATC in the AILS concept?

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Appendix A

Generating the Recorded Intruder Profiles

The intruder path profiles were prerecorded in digital files. These files were based on the simulated flights flown in a manual mode in the same atmospheric conditions used in the tests, light turbulence, and a 10-knot crosswind. Prerecorded flights were made with the intruder track deviation prescribed by each of the seven scenarios of the test. The data in the files were manually manipulated to accomplish the requirements for each data run. This was completed during the period that the experiment was set up, prior to the start of all testing. A total of 896 (7 scenarios $\times$ 2 speeds $\times$ 2 altitudes $\times$ 2 sides $\times$ 16 subjects) intruder path files were generated to support the tests. An example of how the scenarios were set up is illustrated in a step by step manner in figure A1. Figure A2 presents additional details of the process when the intruder crossing is 1500 feet ahead of the primary test airplane.

The process included the following steps (see fig. A1):

1. Record the time history profile of the traffic airplane with experienced pilots flying the simulator to prescribed tracks. This included the seven paths illustrated in figure 15 at both intruder speeds. These runs were recorded for operation to the closest sync point to the runway threshold, i.e. the longest path length, and a run was recorded with the intruder airplane erring from a path on the left runway and one from the path to the right runway.

2. Record pilot flown tracks for the own airplane to be used (only) in setting up the intruder scenarios. These tracks were not used in the actual tests, but were necessary as a template for setting up the encounter scenarios.

3. Select four sync points at which the specified encounter conditions (path crossings) would exist. These are longitudinal distances of the intruder airplane from the runway threshold at which the nominal encounter would take place if no evasion maneuver is executed by the primary test airplane. The points selected were 1.0, 2.3, 3.7, and 5.0 NM from the runway threshold. In each test run involving an intrusion incident, the intruder airplane crossed the path of the primary airplane at one of these longitudinal distances. Different sync points were included so that it would not be obvious to the test subject where the intrusion incident would take place.

4. For each encounter run, select a sync point and plot the path of the intruder airplane (from step 1 above) and the own airplane (from step 2 above) and match points so that the intruder is at the appropriate location relative to the own airplane. For the sync points more distant from the runway threshold, some of the straight in portion of the intruder path data was discarded to appropriately adjust the longitudinal path lengths. Each record in the intruder file included the state information of the intruder airplane and the corresponding location of the own airplane to be used as an index for reading the file and coupling correctly to the location of the own airplane.

5. When the runs did not include a path crossing incident, the longitudinal paths of the two simulated airplanes were coupled so that they both were longitudinally at the sync point distance from the runway threshold simultaneously.

In the real-time operation, the position of the parallel traffic airplane (intruder) was coupled to that of the primary test airplane until a level three alert was issued due to an intrusion incident. The longitudinal position remained coupled throughout the entire run when no intruder warning was initiated. During the operation, until a level three warning was initiated, the parallel traffic position control algorithms (facilitating the simulation) read the real-time longitudinal location of the primary test airplane (own ship) as flown by the pilot test subject. The algorithm then used that longitudinal position of the own ship as the index to read from the prerecorded intruder file created in step 4 above. The corresponding position coordinates and other state information (time, heading, bank, airspeed) of the intruder airplane were read, according to the own ship longitudinal index. The simulation display software then presented the intruder at the appropriate nominal dynamic test locations and states as determined from the prerecorded file. Lateral deviations of the primary test airplane from its nominal path were ignored in the process for determining the position of the traffic airplane. When the level three (red) alert was initiated, the intruder location was uncoupled from that of the own ship and the intruder traffic continued on its prerecorded path, based on time increments. The own ship was expected to maneuver to safety starting at that point.

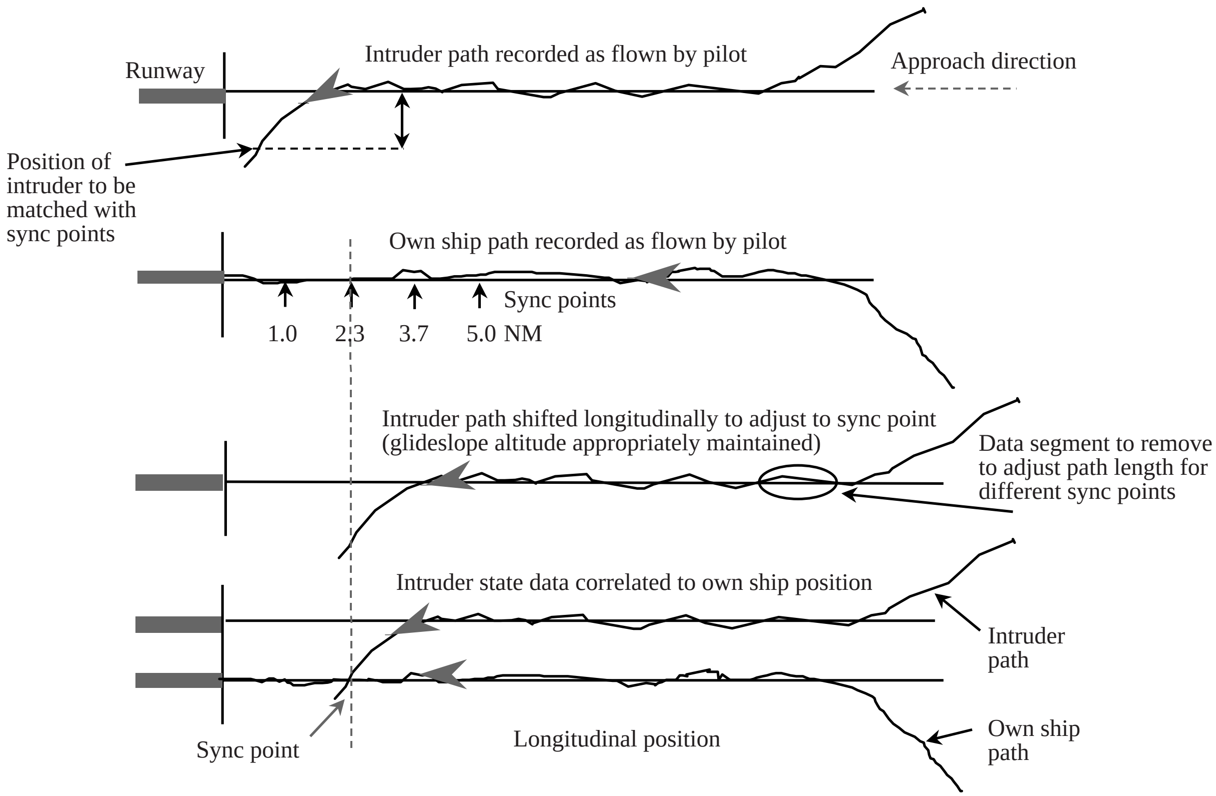


Figure A1. Steps in recording an example TPG file (3400 foot runway spacing).

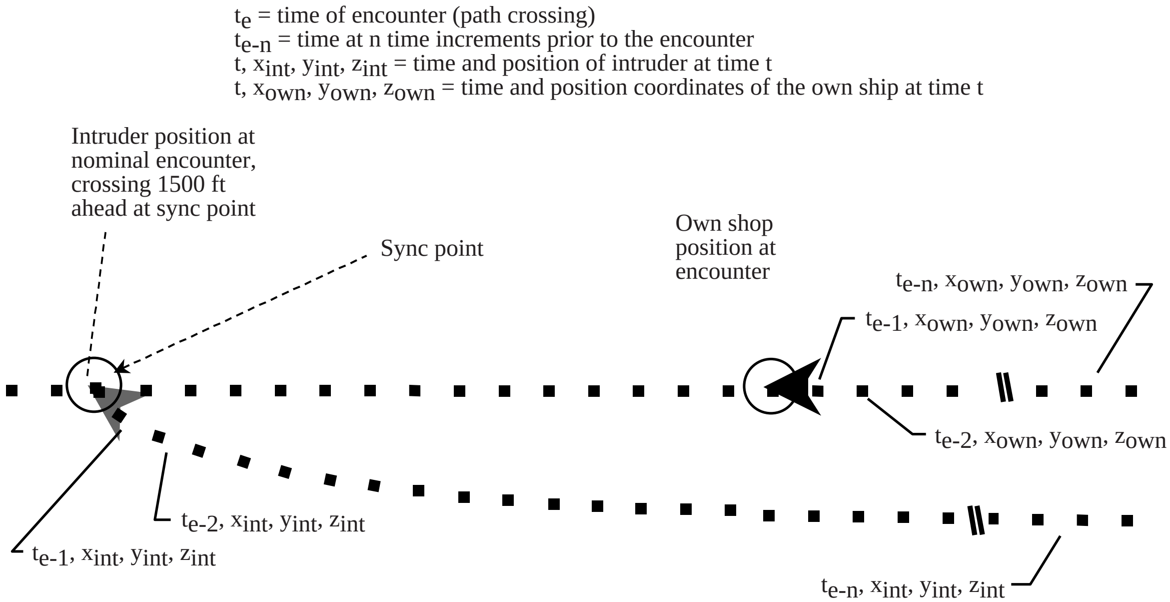


Figure A2. Intruder position as a function of intruder distance from the encounter sync point. TPG's used prerecorded simulator flights.

Appendix B

This appendix consists of three aspects of the pilot debriefing questionnaire session:

- The questionnaire form as it was given to the pilots.
- A compilation of the pilots responses on the form presented on the modified form.
- A list of the comments made on the form, grouped by pilot number.

Pilot responses to the questionnaire are presented on the following pages. Table B1 provides a summary of the background of the pilot subjects.

Table B1. Subject Pilots' Background.

Pilot number	Affiliation	Total Flight Hours	Current Aircraft	Other Aircraft Experience
1	Capt. US Air	8,400	Fk-100	B757, 767, 737, 727, C-130
2	Capt. US Air	13,000	DC-9	B737, 727, C-130
3	Capt. US Air	13,500	Fk100	MD-80, B-737, BAC 1-11, Lear Jet
4	Capt. US Air	22,000	B767/57	B737, DC-9, F-227-500C, DHC-6
5	F.O. AAL	3,600	B727	T37, T38, B52
6	F.O. AAL	12,000	C141A&B	B727-200, B767-200&300, B757
7	F.O. AAL	6,000	B767/757	MD80, B727, F14, F5/T38, F8, A4
8	F.O. UAL	5,000	B727	T28, C-152, Piper Warrior, F-15, T38
9	F.O. AAL	7,167	MD-80	B757/67, PA-44-180, A4, OV-10, AV-8
10	Capt. AAL	15,000	B767/77	A300, DC-10, MD-80, B727, Lear 25
11	F.O. UAL	5,000	B737-300/500	T-1A, E-4B(747), KC-135, T38, CT-39
12	Capt. AAL	10,500	B767/757	DC9-80/83, B737-100/200/300, KC-10
13	Capt. US Air	9,000	B757/767	FK-100, B737-300/300/400, DC-9/MD80
14	Capt. UPS	7,500	B757	B727, B737, T-39, C-130
15	F.O. UAL	5,325	B767/757	DC-10, B727, S-2F, T-33
16	F.O. AAL	13,000	B767/757	B727, B737, CV-580, T-38

Pilot Debriefing Questionnaire

Name:

Mailing Address:

Phone no:

Piloting Experience:

Aircraft Type:	***No. of hours***
____________	___________
____________	____________
____________	____________
____________	____________
____________	____________

Part 1 -- Exploded View Display (2 NM display range) 3400 ft. Runway spacing
Please provide your opinion and evaluations of the 2 NM range navigation display and parallel traffic information presented in that display setup when flying the 3400 ft. runway spacing

The Parallel Traffic Display

1. During the localizer capture, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

2. During the straight-in portion of the approach, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

3. Overall, I found the navigation display of traffic in this mode
   a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

4. The additional workload associated with using the parallel traffic display was
   a. very high b. somewhat high c. moderate d. low e. not noticeable

The Out of the Window View

5. During the localizer capture phase of the simulated flights, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

6. During the straight-in portion of the approach, I looked out of the window for the adjacent traffic
   a. never b. rarely c. occasionally d. frequently e. continually

7. During the evasion maneuver, I looked out of the window
   a. never b. rarely c. occasionally d. frequently e. continually

8. After the evasion maneuver was completed, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

Alerts

9. Was the time available after the alert was given adequate to maneuver to safety?
   a. inadequate b. somewhat inadequate c. about right d. somewhat excessive e. highly excessive

10. The alphanumeric “Turn Climb” presented in the Primary Flight Display was
   a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

11. The “Turn Climb, Turn Climb” computer-driven voice message spoken during the alert was
   a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

Intruder Aircraft Predicted Path Information

12. On receiving the intruder alert, did you look at any information in the displays before making a turning or climbing control input?

a. never b. rarely c. occasionally d. frequently e. always

13. Was acquiring information on the probable path of the intruder important in avoiding a collision?

a. never b. rarely c. occasionally d. frequently e. always

14. Was the display of the predicted path of the intruder helpful to you in deciding **whether** to maneuver?

a. never b. rarely c. occasionally d. frequently e. always

15. Was the display of the predicted path of the intruder helpful in determining the nature of the maneuver you executed?

a. never b. rarely c. occasionally d. frequently e. always

16. I would recommend that the relative path display showing the predicted path of the intruder be (given)

a. eliminated b. majors mods c. minor mods d. kept as is **16a. suggest mods on back**

Part 1 cont. -- Exploded View Display (2 NM display range) 3400 ft. Runway spacing

17. Were there instances that you felt that in an actual flight situation you would not have followed the procedures as directed, because of the information presented.

a. Always agreed with the display and procedure b. occasionally I felt I would have broken off when no red alert was given c. occasionally I felt that a red alert was given when it was not clear that a break off was necessary.

Comment:

18. Please suggest any modifications you feel would improve the displays and procedures.

Space for additional comments on any of the previous questions and any other observations on this portion of the experiment:

Part 2 -- Exploded view (2 NM display range) 2500 ft. Runway spacing
Please provide your opinion and evaluations of the 2 NM range navigation display and parallel traffic information presented in that display setup when flying the 2500 ft. runway spacing.

The Parallel Traffic Display

1. During the localizer capture, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

2. During the straight in portion of the approach, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

3. Overall, I found the navigation display of traffic in this mode
   a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

4. The additional workload associated with using the parallel traffic display was
   a. very high b. somewhat high c. moderate d. low e. not noticeable

The Out of the Window View

5. During the localizer capture phase, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

6. During the straight-in portion of the approach, I looked out of the window for the adjacent traffic
   a. never b. rarely c. occasionally d. frequently e. continually

7. During the evasion maneuver, I looked out of the window
   a. never b. rarely c. occasionally d. frequently e. continually

8. After the evasion maneuver was completed, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

Alerts

9. Was the time available after the alert was given adequate to maneuver to safety?
   a. inadequate b. somewhat inadequate c. about right d. somewhat excessive e. highly excessive

10. The alphanumeric “Turn Climb” presented in the Primary Flight Display was
    a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

11. The “Turn Climb” computer-driven voice message spoken during the alert was
    a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

Intruder Predicted Path Information

12. On receiving the intruder alert, did you look at any information in the displays before making a turning or climbing control input?
    a. never b. rarely c. occasionally d. frequently e. always

13. Was acquiring information on the probable path of the intruder important in avoiding a collision?

a. never b. rarely c. occasionally d. frequently e. always

14. Was the display of the predicted path of the intruder helpful to you in deciding **whether** to maneuver?

a. never b. rarely c. occasionally d. frequently e. always

15. Was the display of the predicted path of the intruder helpful in determining the nature of the maneuver you executed?

a. never b. rarely c. occasionally d. frequently e. always

16. I would recommend that the relative path display showing the predicted path of the intruder be (given)

a. eliminated b. major mods c. minor mods d. kept as is **16a.** ***suggest mods on back***

Part 2 cont. -- Exploded view (2 NM display range) 2500 ft. Runway spacing

17. Were there instances that you felt that in an actual flight situation you would not have followed the procedures as directed, because of the information presented.

a. Always agreed with the display and procedure b. occasionally I felt I would have broken off when no red alert was given c. occasionally I felt that a red alert was given when it was not clear that a break off was necessary.

Comment:

18. Please suggest any modifications you feel would improve the displays and procedures.

Space for additional comments on any of the previous questions and any other observations on this portion of the experiment:

Part 3 -- Wide field view (10 NM display range) 3400 ft. Runway spacing
Please provide your opinion and evaluations of the 10 nm range navigation display and parallel traffic information presented in that display setup when flying the 3400 ft. runway spacing.

The Parallel Traffic Display

1. During the localizer capture, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

2. During the straight-in portion of the approach, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

3. Overall, I found the navigation display of traffic in this mode
   a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

4. The additional workload associated with using the parallel traffic display was
   a. very high b. somewhat high c. moderate d. low e. not noticeable

The Out of the Window View

5. During the localizer capture phase, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

6. During the straight-in portion of the approach, I looked out of the window for the adjacent traffic
   a. never b. rarely c. occasionally d. frequently e. continually

7. During the evasion maneuver, I looked out of the window
   a. never b. rarely c. occasionally d. frequently e. continually

8. After the evasion maneuver was completed, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

Alerts

9. Was the time available after the alert was given adequate to maneuver to safety?
   a. inadequate b. somewhat inadequate c. about right d. somewhat excessive
   e. highly excessive

10. The alphanumeric "Turn Climb" presented in the Primary Flight Display was
    a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

11. The "Turn Climb" computer-driven voice message spoken during the alert was
    a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

Intruder Path Information

12. On receiving the intruder alert, did you look at any information in the displays before making a turning or climbing control input?

a. never b. rarely c. occasionally d. frequently e. always

13. Was acquiring information on the path of the intruder an important step in avoiding a collision?

a. never b. rarely c. occasionally d. frequently e. always

14. Was the display of the intruder helpful to you in deciding whether to maneuver?

a. never b. rarely c. occasionally d. frequently e. always

15. Was the display of the intruder helpful in determining the nature of the maneuver you executed?

a. never b. rarely c. occasionally d. frequently e. always

Part 3 cont. -- Wide field view (10 NM display range)   3400 ft. Runway spacing

16. Were there instances that you felt that in an actual flight situation you would not have followed the procedures as directed, because of the information presented.

a. Always agreed with the display and procedure b. occasionally I felt I would have broken off when no red alert was given c. occasionally I felt that a red alert was given when it was not clear that a break off was necessary.

comment:

17. Please suggest any modifications you feel would improve the displays and procedures.

Space for additional comments on any of the previous questions and any other observations on this portion of the experiment:

Part 4 -- Wide field view (10 NM display range) 2500 ft. Runway spacing
Please provide your opinion and evaluations of the 10 NM range navigation display and parallel traffic information presented in that display setup when flying the 2500 ft. runway spacing.

The Parallel Traffic Display

1. During the localizer capture, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

2. During the approach, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

3. Overall, I found the navigation display of traffic in this mode
   a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

4. The additional workload associated with using the parallel traffic display was
   a. very high b. somewhat high c. moderate d. low e. not noticeable

The Out of the Window View

5. During the localizer capture phase, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

6. During the straight-in portion of the approach, I looked out of the window for the adjacent traffic
   a. never b. rarely c. occasionally d. frequently e. continually

7. During the evasion maneuver, I looked out of the window
   a. never b. rarely c. occasionally d. frequently e. continually

8. After the evasion maneuver was completed, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

Alerts

9. Was the time available after the alert was given adequate to maneuver to safety?
   a. inadequate b. somewhat inadequate c. about right d. somewhat excessive
   e. highly excessive

10. The alphanumeric “Turn Climb” presented in the Primary Flight Display was
    a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

11. The “Turn Climb” computer-driven voice message spoken during the alert was
    a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

Intruder Path Information

12. On receiving the intruder alert, did you look at any information in the displays before making a turning or climbing control input?
    a. never b. rarely c. occasionally d. frequently e. always

13. Was acquiring information on the path of the intruder important in avoiding a collision?
a. never b. rarely c. occasionally d. frequently e. always

14. Was the display of the intruder helpful to you in deciding whether to maneuver?
a. never b. rarely c. occasionally d. frequently e. always

15. Was the display of the intruder helpful in determining the nature of the maneuver you executed?
a. never b. rarely c. occasionally d. frequently e. always

Part 4 cont. -- Wide field view (10 NM display range) 2500 ft. Runway spacing

16. Were there instances that you felt that in an actual flight situation you would not have followed the procedures as directed because of the information presented.

a. Always agreed with the display and procedure b. occasionally I felt I would have broken off when no red alert was given c. occasionally I felt that a red alert was given when it was not clear that a break off was necessary.
comments:

17. Please suggest any modifications you feel would improve the displays and procedures.

Space for additional comments on any of the previous questions and any other observations on this portion of the experiment:

Part 5-- The Simulator
Please provide your evaluation of the simulator and its appropriateness for evaluating pilot performance in the tasks with the display innovations and procedures presented in these tests. Also, please keep in mind that this simulator is a research facility and not a training simulator.

The Simulator

1. I found the fidelity of the simulator in terms of allowing an accurate evaluation of my performance of the task?
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

2. The fidelity of the simulator biased my performance of the task compared to that in flight as follows:
3. a. grossly degraded b. slightly degraded c. no difference d. slightly improved e. grossly improved

3. I have on occasions operated as a pilot in a part-task simulator of somewhat similar fidelity
a. never b. once before c. on a number of occasions

The Flight Controls (referencing a medium transport of the Boeing 737 class)

4. The manual control mode used in the tests was
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

5. The response of the simulated airplane to roll control inputs was
a. very low b. slightly low c. about right d. slightly high e. excessively high

6. The response of the simulated airplane to pitch control inputs was
a. very low b. slightly low c. about right d. slightly high e. excessively high

7. The climbing performance of the simulated airplane was
a. very low b. slightly low c. about right d. slightly high e. excessively high

The Control Actuator Levers

8. I found use of the side stick controller
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

9. How long did it take you to feel comfortable with the side stick controller?
a. almost immediately b. Less than 5 min. c. Less than 30 minutes d. an hour or more
e. never did

The Flight Displays

10. The flight displays provided the information I needed in a manner I would describe as
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

11. In terms of the tasks required in this test, the flight director roll command was
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

12. In terms of the tasks required in this test, the flight director pitch command was
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

13. The out-of-the-window scene was
a. not relevant b. somewhat relevant c. no opinion d. somewhat necessary e. essential

14. In terms of the task required in this test, the fidelity of the out-of-the-window scene was
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

Look Point Tracking

15. Was your performance during the evasion maneuver hampered by the eye tracking equipment?
a. not at all b. very little c. somewhat d. considerably

16. Did the eye tracking equipment interfere with your ability to perform any of the required task?
a. not at all b. very little c. somewhat d. considerably
Comment:

Part 6 -- Miscellaneous
Please provide your evaluation on the aspects addressed below

The Localizer Sensitivity

1. The difficulty of capturing the localizer compared to conventional ILS operations was
a. much more b. somewhat more c. about the same d. slightly less e. significantly less

2. The difficulty of flying the localizer after capture, compared to conventional ILS, was
a. much more b. somewhat more c. about the same d. slightly less e. significantly less

3. Immediately after localizer capture, prior to glideslope capture, the sensitivity of the localizer was
a. much too low b. a little too low c. just about right d. a little too high e. much too high

4. After glideslope capture the sensitivity of the localizer was
a. much too low b. a little too low c. just about right d. a little too high e. much too high

Special Display Features

5. The “break-off” heading bug (the barber pole striped red and white indicator) in the navigation display was
a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

6. Retracting the flight director command bars when break-off alerts were given was
a. distracting b. no help c.somewhat helpful d. very helpful e. essential for safe operation

Other special features related to the parallel runway operation

7. The escape maneuver was
a. highly favorable b. favorable c. adequate d. somewhat adequate e. unacceptable

8. The fact that the escape maneuver resulted in a belly-up condition was
a. unacceptable b. somewhat of concern c. of no concern d. favorable e. highly favorable

9. My opinion of the accelerating, turning, climbing procedure used for escape, in the real world it would be
a. highly favorable b. favorable c. adequate d. somewhat objectionable e. unacceptable

10. In my opinion, the fact that the pilot was not expected to selected a maneuver and direction to avoid an intruder was
a. highly favorable b. favorable c. adequate d. somewhat objectionable e. unacceptable

11. The one dot localizer alert was designed into the concept. My opinion is that this feature was
a. unacceptable b. somewhat objectionable c. adequate d. favorable e. highly favorable

12. The two dot localizer alert requiring a breakoff of the approach was in my opinion
a. unacceptable b. somewhat objectionable c. adequate d. favorable e. highly favorable

13. The relative path vector presenting the projected path of the intruder relative to my own projected path was
a. highly favorable b. favorable c. adequate d. somewhat objectionable e. unacceptable

14. Compared to a more conventional path vector showing the projected ground track of the intruder, my opinion is that the relative path vector presentation was
a. highly favorable b. favorable c. adequate d. somewhat adequate e. unacceptable

15. In my opinion presenting a more conventional projected ground track of the intruder instead of the relative path information would be
a. unacceptable b. somewhat objectionable c. adequate d. favorable e. highly favorable

This space is provided for additional comments on any earlier questions or any other aspect of the experiment.

Part 1 -- Exploded View Display (2 NM display range) ***3400 ft. Runway spacing***
Please provide your opinion and evaluations of the 2 NM range navigation display and parallel traffic information presented in that display setup when flying the 3400 ft. runway spacing

The Parallel Traffic Display

1. During the localizer capture, I looked at the adjacent-traffic display in the ND
a. never b. rarely c. occasionally d. frequently e. continually

a. 1,3,5,6	**b. 2,9**	**c. 4,7,8,10,12,13,14**	**d. 11,15,16**	**e.**

2. During the straight-in portion of the approach, I looked at the adjacent-traffic display in the ND
a. never b. rarely c. occasionally d. frequently e. continually

a.	**b. 3**	**c. 2,3,4,5,6,8,9,10,14**	**d. 1,7 ,11,12,13,15,16**	**e.**

3. Overall, I found the navigation display of traffic in this mode
a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

a. b. c. 3,10,13,9 d. 1,2,5 6,7,8,11,12,15,16 e. 4,14

4. The additional workload associated with using the parallel traffic display was
a. very high b. somewhat high c. moderate d. low e. not noticeable

a. b. 7,10 c. 1,5 ,11,12,15 d. 2,3,4,6,8,14,16 e. 9,13

The Out-of-the-Window View

5. During the localizer capture phase of the simulated flights, I looked out of the window for traffic
a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,5,6,9,10,13,14 b. 7,8,11,12,15 c. d. 16 e.

6. During the straight-in portion of the approach, I looked out of the window for the adjacent traffic
a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,4,5,6,9,10,13,14 b. 7,8,11,12,15,16 c. 3 d. e.

7. During the evasion maneuver, I looked out of the window
a. never b. rarely c. occasionally d. frequently e. continually

a. 3,4,5,6,9,10,12,13,14,16 b. 1,2,7,8 ,11,15 c. d. e.

8. After the evasion maneuver was completed, I looked out of the window for traffic
a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,5,9,10,14,16 b. 6,7,8,11,12,13 c. d. 15 e.

Alerts

9. Was the time available after the alert was given adequate to maneuver to safety?
a. inadequate b. somewhat inadequate c. about right d. somewhat excessive e. highly excessive

a. b. c. 1,3,4,5,6,7,8,9 ,11,10,12,13,15,16 d. 2,14 e.

10. The alphanumeric "Turn Climb" presented in the Primary Flight Display was
a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a. b. c. 8,10,14 d. 1,6,7,9 e. 2,3,4,5,11,12,13,15,16

11. The "Turn Climb, Turn Climb" computer-driven voice message spoken during the alert was
a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a. b. c. 5,6,8 d. 1,2,3,7,9,12,14 e. 4,11,10,13,15,16

Intruder Aircraft Predicted Path Information

12. On receiving the intruder alert, did you look at any information in the displays before making a turning or climbing control input?
a. never b. rarely c. occasionally d. frequently e. always

a. 3,5,6,8,10,11,12,13,15 b. 2,4,9,14,16 c. 7 d. 1 e.

13. Was acquiring information on the probable path of the intruder important in avoiding a collision?
a. never b. rarely c. occasionally d. frequently e. always

a. 2,8 b. 9,13,14 c. 3,5,6,7,10,12 d. 1,7,16 e. 4,11,15

14. Was the display of the predicted path of the intruder helpful to you in deciding **whether** to maneuver?

a. never b. rarely c. occasionally d. frequently e. always

a. 2,4,5,6,8,11,10,15	**b. 9,14**	**c. 3,12,13**	**d. 1,7,16**	**e.**

15. Was the display of the predicted path of the intruder helpful in determining the nature of the maneuver you executed?

a. never b. rarely c. occasionally d. frequently e. always

a. 2,10,11,14	**b. 9,13,16**	**c. 3,5,6,12**	**d. 1,8**	**e. 4,7,15**

16. I would recommend that the relative path display showing the predicted path of the intruder be (given)

a. eliminated b. majors mods c. minor mods d. kept as is

16a. suggest mods on back

a. 13	**b.**	**c. 3,8,15**	**d. 1,2,4,5,6,9,10,11,12,14,16**	**e.**

Part 1 cont. -- Exploded View Display (2 NM display range) 3400 ft. Runway spacing

17. Were there instances that you felt that in an actual flight situation you would not have followed the procedures as directed, because of the information presented.
a. Always agreed with the display and procedure b. occasionally I felt I would have broken off when no red alert was given c. occasionally I felt that a red alert was given when it was not clear that a break off was necessary.

a. 1,2,4,6,10,11,12,13,14,15	**b. 3,5,7,8,9,16**	**c.**	**d.**	**e.**

Comment:

18. Please suggest any modifications you feel would improve the displays and procedures.

Space for additional comments on any of the previous questions and any other observations on this portion of the experiment:

Part 2 -- Exploded view (2 NM display range) 2500 ft. Runway spacing
Please provide your opinion and evaluations of the 2 NM range navigation display and parallel traffic information presented in that display setup when flying the 2500 ft. runway spacing.

The Parallel Traffic Display

1. During the localizer capture, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

a. 3,5 b. 2,6,9 c. 1,4,7 ,8,13,14,15 d. 10,11,12,16 e.

2. During the straight-in portion of the approach, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

a. b. 4 c. 2,3,5,6,8,9,10,13,14 d. 1,7,11,12,15,16 e.

3. Overall, I found the navigation display of traffic in this mode
   a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

a. b. c. 3,6,9 d. 1,2,5,7,8,10,12,13,14,15,16 e. ,4,11

4. The additional workload associated with using the parallel traffic display was
   a. very high b. somewhat high c. moderate d. low e. not noticeable

a. b. 7 c. 1,4,5,10,11,12,15 d. 2,3,6,8,9,14,16 e. 13

The Out-of-the-Window View

5. During the localizer capture phase, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,6,9,10,13,14 b. 5,7,8,11,12,15,16 c. d. e.

6. During the straight-in portion of the approach, I looked out of the window for the adjacent traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,9,10,14 b. 6,7,8,11,12,13,15,16 c. 5 d. e.

7. During the evasion maneuver, I looked out of the window
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,5,6,9,12,13,14,16 b. 7,8,10,11,15 c. d. e.

8. After the evasion maneuver was completed, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,6,9,10,13,14,16 b. 11 c. 7,5,8,15 d. e.

Alerts

9. Was the time available after the alert was given adequate to maneuver to safety?
   a. inadequate b. somewhat inadequate c. about right d. somewhat excessive e. highly excessive

a. b. c. 1,3,4,5,6,7,8,9,10,11,13,15,16 d. 2,14 e.

10. The alphanumeric "Turn Climb" presented in the Primary Flight Display was
   a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a. b. c. 6,8,10,14 d. 1,7,9 e. 2,3,4,5,11,12,13,15,16

11. The "Turn Climb" computer-driven voice message spoken during the alert was
   a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a.	**b.**	**c. 5,6,8**	**d. 1,2,3,7,9,10,12,14**	**e. 4,11,13,15,16**

Intruder Predicted Path Information

12. On receiving the intruder alert, did you look at any information in the displays before making a turning or climbing control input?

a. never b. rarely c. occasionally d. frequently e. always

a. 3,5,6,8,10,13	**b. 2,4,9,11,14,16**	**c. 7,12**	**d. 1**	**e. 15**

13. Was acquiring information on the probable path of the intruder important in avoiding a collision?

a. never b. rarely c. occasionally d. frequently e. always

a. 2,8,9	**b. 13,14**	**c. 3,5,6,11**	**d. 7,10,12,16**	**e. 1,4,15**

14. Was the display of the predicted path of the intruder helpful to you in deciding **whether** to maneuver?

a. never b. rarely c. occasionally d. frequently e. always

a. 2,4,5,6,8,9,10 ,11	**b.**	**c. 3,13,14,15**	**d. 7,12,16**	**e. 1**

15. Was the display of the predicted path of the intruder helpful in determining the nature of the maneuver you executed?

a. never b. rarely c. occasionally d. frequently e. always

a. 2,3,5,9,11,12,16	**b. 6,14**	**c. ,13**	**d. 4,7,8,10**	**e. 1,15**

16. I would recommend that the relative path display showing the predicted path of the intruder be (given)

a. eliminated b. major mods c. minor mods d. kept as is **16a.** ***suggest mods on back***

a.	**b.**	**c. 4,8,10,15**	**d. 1,2,3,5,6,7,9 ,11,12,13,14,16**	**e.**

Part 2 cont. -- Exploded view (2 NM display range) 2500 ft. Runway spacing

17. Were there instances that you felt that in an actual flight situation you would not have followed the procedures as directed, because of the information presented.

a. Always agreed with the display and procedure b. occasionally I felt I would have broken off when no red alert was given c. occasionally I felt that a red alert was given when it was not clear that a break off was necessary.

a. 1,3,6,10,11,12,13,14	**b. 2,4,5,7,8,9,16**	**c. 15**	**d.**	**e.**

Comment:

18. Please suggest any modifications you feel would improve the displays and procedures.

Space for additional comments on any of the previous questions and any other observations on this portion of the experiment:

Part 3 -- Wide field view (10 NM display range) 3400 ft. Runway spacing
Please provide your opinion and evaluations of the 10 NM range navigation display and parallel traffic information presented in that display setup when flying the 3400 ft. runway spacing.

The Parallel Traffic Display

1. During the localizer capture, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,3 b. 2,5,9,10,14 c. 6,8,11,12,13,15 d. 4,7,16 e.

2. During the straight-in portion of the approach, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

a. b. 9 c. 1,2,3,4,5,6,8,10,13,14,15,16 d. 7,11,12 e.

3. Overall, I found the navigation display of traffic in this mode
   a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

a. b. 5,9,14 c. 1,2,3,6,7,10,12 d. 4,8 ,11,13,15,16 e.

4. The additional workload associated with using the parallel traffic display was
   a. very high b. somewhat high c. moderate d. low e. not noticeable

a. b. 5 c. 1,9,10,12,13,14,15 d. 2,3,4,6,7,8 ,11,16 e.

The Out-of-the-Window View

5. During the localizer capture phase, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,5,6,9,10,13,14 b. 8 ,11,12,15 c. 7,16 d. e.

6. During the straight-in portion of the approach, I looked out of the window for the adjacent traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 2,3,4,5,9,10,13,14,16 b. 1,6,8 ,11,15 c. 7,12 d. e.

7. During the evasion maneuver, I looked out of the window
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,5,6,8,9,10,12,14,16 b. 7 ,11,13,15 c. d. e.

8. After the evasion maneuver was completed, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,5,6,8,9,10,13,14,16 b. 7,11,12 c. d. 15 e.

Alerts

9. Was the time available after the alert was given adequate to maneuver to safety?
   a. inadequate b. somewhat inadequate c. about right d. somewhat excessive e. highly excessive

a. b. 4 c. 1,3,5,6,7,8,9,10 ,11,13,15,16 d. 2,12,14 e.

10. The alphanumeric "Turn Climb" presented in the Primary Flight Display was
   a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a. b. c. 8,14 d. 1,4,7,9,10 e. 2,3,5,6 ,11,12 ,13,15,16

11. The "Turn Climb" computer-driven voice message spoken during the alert was

a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a.	**b.**	**c. 6**	**d. 1,2,4,5,7,8,9,10,12,14**	**e. 3,11,13,15,16**

Intruder Path Information

12. On receiving the intruder alert, did you look at any information in the displays before making a turning or climbing control input?

a. never b. rarely c. occasionally d. frequently e. always

a. 3,4,5,6,8,9,10,11,13,15,16	**b. 1,2 ,12,14**	**c. 7**	**d.**	**e.**

13. Was acquiring information on the path of the intruder an important step in avoiding a collision?

a. never b. rarely c. occasionally d. frequently e. always

a. 2,6,8,9,11,13	**b. 3,4,5,12,14,16**	**c.**	**d. 1,10**	**e. 7,15**

14. Was the display of the intruder helpful to you in deciding whether to maneuver?

a. never b. rarely c. occasionally d. frequently e. always

a. 6,8,9,10,11,12	**b. 1,2,3,4,5,13,14**	**c. 16**	**d.**	**e. 7,15**

15. Was the display of the intruder helpful in determining the nature of the maneuver you executed?

a. never b. rarely c. occasionally d. frequently e. always

a. 2,5,6,8,9,10,11,12,13,15,16	**b. 1,3,14**	**c. 4**	**d. 7**	**e.**

Part 3 cont. -- Wide field view (10 NM display range) 3400 ft. Runway spacing

16. Were there instances that you felt that in an actual flight situation you would not have followed the procedures as directed, because of the information presented.

a. Always agreed with the display and procedure b. occasionally I felt I would have broken off when no red alert was given c. occasionally I felt that a red alert was given when it was not clear that a break off was necessary.

comment:

a. 1,2,3,5,6,7,10,11,12,13,14,15	**b. 4,8,9,16**	**c.**	**d.**	**e.**

17. Please suggest any modifications you feel would improve the displays and procedures.

Space for additional comments on any of the previous questions and any other observations on this portion of the experiment:

Part 4 -- Wide field view (10 NM display range) 2500 ft. Runway spacing
Please provide your opinion and evaluations of the 10 nm range navigation display and parallel traffic information presented in that display setup when flying the 2500 ft. runway spacing.

The Parallel Traffic Display

1. During the localizer capture, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,3 b. 2,4,5,6,7,9,12 c. 8,10,11,13,14,15,16 d. e.

2. During the approach, I looked at the adjacent-traffic display in the ND
   a. never b. rarely c. occasionally d. frequently e. continually

a. b. 3,9 c. 2,4,5,6,8,10,12,14,15,16 d. 1,7,11,13 e.

3. Overall, I found the navigation display of traffic in this mode
   a. distracting b. of little help c. somewhat helpful d. quite helpful e. essential

a. 9 b. 2,3,5 c. 1,6,8,12,13,14,15,16 d. 4,7,10,11 e.

4. The additional workload associated with using the parallel traffic display was
   a. very high b. somewhat high c. moderate d. low e. not noticeable

a. 5 b. 9 c. 1,7,8,10,12,14,15 d. 2,3,6,11,16 e. 4,13

The Out-of-the-Window View

5. During the localizer capture phase, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,5,7,8,9,10,13,14 b. 4,6,11,12,15 c. 16 d. e.

6. During the straight-in portion of the approach, I looked out of the window for the adjacent traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 4,5,9,10,13,14 b. 2,3,7,11,12,16 c. 1,6,8,15 d. e.

7. During the evasion maneuver, I looked out of the window
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,5,6,7,9,10,12,13,14,16 b. 8,11,15 c. d. e.

8. After the evasion maneuver was completed, I looked out of the window for traffic
   a. never b. rarely c. occasionally d. frequently e. continually

a. 1,2,3,4,5,6,9,10,14,16 b. 11,12,13 c. 7,8 d. 15 e.

Alerts

9. Was the time available after the alert was given adequate to maneuver to safety?
   a. inadequate b. somewhat inadequate c. about right d. somewhat excessive
e. highly excessive

a. b. c. 1,3,4,5,6,7,8,9,10,11,13,15,16 d. 2,12,14 e.

10. The alphanumeric "Turn Climb" presented in the Primary Flight Display was
   a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a. b. c. 8,14 d. 1,4,7,9,10 e. 2,3,5,6,11,12,13,15,16

11. The "Turn Climb" computer-driven voice message spoken during the alert was
   a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a.	**b.**	**c. 6,8**	**d. 1,2,5,7,9,10,12,14**	**e. 3,4 ,11,13,15,16**

Intruder Path Information

12. On receiving the intruder alert, did you look at any information in the displays before making a turning or climbing control input?
a. never b. rarely c. occasionally d. frequently e. always

a. 2,3,5,6,8,10,11,12,15,16	**b. 4,9,13,14**	**c. 1**	**d. 7**	**e.**

13. Was acquiring information on the path of the intruder important in avoiding a collision?
a. never b. rarely c. occasionally d. frequently e. always

a. 2,3,5,6,8,9,13,14	**b. 4,11,12,14,16**	**c.**	**d. 1,7,10**	**e. 15**

14. Was the display of the intruder helpful to you in deciding whether to maneuver?
a. never b. rarely c. occasionally d. frequently e. always

a. 2,3,5,8,9,10,11,12,13,15	**b. 6,14,16**	**c. 7**	**d. 1,4**	**e.**

15. Was the display of the intruder helpful in determining the nature of the maneuver you executed?
a. never b. rarely c. occasionally d. frequently e. always

a. 2,3,5,8,9,11,12,13,14,15	**b. 4,6,16**	**c.**	**d. 1,7,10**	**e.**

Part 4 cont. -- Wide field view (10 NM display range) 2500 ft. Runway spacing

16. Were there instances that you felt that in an actual flight situation you would not have followed the procedures as directed because of the information presented.
a. Always agreed with the display and procedure b. occasionally I felt I would have broken off when no red alert was given c. occasionally I felt that a red alert was given when it was not clear that a break off was necessary.
comments:

a. 1,3,6,7,11,12,13,14,15	**b. 4,5,8,9,10,16**	**c.**	**d.**	**e.**

17. Please suggest any modifications you feel would improve the displays and procedures.

Space for additional comments on any of the previous questions and any other observations on this portion of the experiment:

Part 5 -- The Simulator
Please provide your evaluation of the simulator and its appropriateness for evaluating pilot performance in the tasks with the display innovations and procedures presented in these tests. Also, please keep in mind that this simulator is a research facility and not a training simulator.

The Simulator

1. I found the fidelity of the simulator in terms of allowing an accurate evaluation of my performance of the task?
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

a. 6 b. 8 c. 9,14 d. 1,2,3,4,5,7,10,13,15,16 e. 11,12

2. The fidelity of the simulator biased my performance of the task compared to that in flight as follows
a. grossly degraded b. slightly degraded c. no difference d. slightly improved
e. grossly improved

a. b. 3,4,10,14,16 c. 2,6,7,11,13,15 d. 1,5,9,12 e. 8

3. I have on occasions operated as a pilot in a part-task simulator of somewhat similar fidelity
a. never b. once before c. on a number of occasions

a. 5,7,15,16 b. 3,14 c. 1,2,4,6,8,9,10,11,12,13

The Flight Controls (referencing a medium transport of the Boeing 737 class)

4. The manual control mode used in the tests was
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

a. b. 4,10 c. 3,6,7,8,9,14,15,16 d. 2,5,1 e. 1,12,13

5. The response of the simulated airplane to roll control inputs was
a. very low b. slightly low c. about right d. slightly high e. excessively high

a. 16 b. 1,2,3,4,6,8,10,14,15 c. 7,9,11,12,13 d. 5 e.

6. The response of the simulated airplane to pitch control inputs was
a. very low b. slightly low c. about right d. slightly high e. excessively high

a. b. 15 c. 1,3,4,5,7,9,10,11,12,13,14,16 d. 2,6,8 e.

7. The climbing performance of the simulated airplane was
a. very low b. slightly low c. about right d. slightly high e. excessively high

a. b. 2,3,10,11,16 c. 4,5,6,7,8,9,12,13,14,15 d. e.

The Control Actuator Levers

8. I found use of the side stick controller
a. unacceptable b. somewhat adequate c. adequate d. favorable e. highly favorable

a. b. c. 6,9 d. 2,3,4,14,15 e. 1,5,7,8,11,12,13,16

9. How long did it take you to feel comfortable with the side stick controller?
a. almost immediately b. Less than 5 min. c. Less than 30 minutes d. an hour or more
e. never did

a. 1,3,4,7,11,13,16 b. 2,5,6,8,9,15 c. ,12,14 d. e.

The Flight Displays

10. The flight displays provided the information I needed in a manner I would describe as

a.	b.	c. 1,3,4,5,6,7,8,9,10,11,12,13,14,15,16	d. 2	e.

4. After glideslope capture the sensitivity of the localizer was
a. much too low b. a little too low c. just about right d. a little too high
e. much too high

a.	b.	c. 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	d.	e.

Special Display Features

5. The "break-off" heading bug (the barber pole striped red and white indicator) in the navigation display was
a. distracting b. no help c. somewhat helpful d. very helpful e. absolutely essential

a.	b.	c. 6	d. 3,7,8,9,10,14,15	e. 1,2,4,5,11,12,13,16

6. Retracting the flight director command bars when break-off alerts were given was
a. distracting b. no help c. somewhat helpful d. very helpful
e. essential for safe operation

a.	b. 1,2,6,8,10	c. 5,12,14	d. 3,4,7,13,15,16	e. 9,11

Other special features related to the parallel runway operation

7. The escape maneuver was
a. highly favorable b. favorable c. adequate d. somewhat adequate e. unacceptable

a. 5,11,12,14	b. 1,2,7,10,15	c. 3,6,9,13,16	d. 4,8	e.

8. The fact that the escape maneuver resulted in a belly-up condition was
a. unacceptable b. somewhat of concern c. of no concern d. favorable
e. highly favorable

a.	b. 2,5,8,9,13	c. 1,3,4,6,7,10,11,12,14,15	d.16	e.

9. My opinion of the accelerating, turning, climbing procedure used for escape, in the real world it would be
a. highly favorable b. favorable c. adequate d. somewhat objectionable
e. unacceptable

a. 5,14	b. 1,2,4,7,11,12,13,15	c. 6	d. 3,8,9,10,16	e.

10. In my opinion, the fact that the pilot was not expected to selected a maneuver and direction to avoid an intruder was
a. highly favorable b. favorable c. adequate d. somewhat objectionable
e. unacceptable

a. 2,5,10,11,12,13	b. 1,4,6,9,14,15,16	c. 3,7	d. 8	e.

11. The one dot localizer alert was designed into the concept. My opinion is that this feature was
a. unacceptable b. somewhat objectionable c. adequate d. favorable
e. highly favorable

a.	b.	c. 1,2,8	d. 3,4,5,6,7,9,10,12,14,15	e. 11,13,16

12. The two dot localizer alert requiring a breakoff of the approach was in my opinion
a. unacceptable b. somewhat objectionable c. adequate d. favorable
e. highly favorable

a.	b. 4	c.	d. 1,2,7,8,9,12,14	e. 3,5,6,10,16,11,13,15

13. The relative path vector presenting the projected path of the intruder relative to my own projected path was

a. highly favorable b. favorable   c. adequate   d. somewhat objectionable
e. unacceptable

a. 1,3,5,6,7,8,10,11,12,14,15,16	b. 2,4,9,13	c.	d.	e.

14. Compared to a more conventional path vector showing the projected ground track of the intruder, my opinion is that the relative path vector presentation was

a. highly favorable b. favorable   c. adequate   d. somewhat adequate   e. unacceptable

a. 1,3,4,5,7,8,9,10,11,12,14,15	b. 2,6,13,16	c.	d.	e.

15. In my opinion presenting a more conventional projected ground track of the intruder instead of the relative path information would be

a. unacceptable b. somewhat objectionable c. adequate   d. favorable
e. highly favorable

a. 1,5,6,8,9,14,15	b.2,4,7,10,12,13	c. 3,11,16	d.	e.

This space is provided for additional comments on any earlier questions or any other aspect of the experiment.

Pilot Comments from the Debriefing Questionnaire Forms

<u>Pilot # 1</u>

Part 1   2 NM range   3400 ft rwy spacing

Q. #18

Drop the flight control movement indicator from the top right corner of the attitude display. I don't need an indication of normal flight control movement flashing in the corner of my vision.

Part 2   2 NM range   2500 ft rwy spacing

Q.#11

"Turn, Climb" needs to be louder.

Q.# 18

On final approach there are 4 lines displayed in front of the aircraft (symbol in the ND).
I think only 2 would suffice. Say when Loc. comes in view, FMC disappears with RW CL, so you would have one course line with the trend vector.

Part 3 10 NM range   3400 ft. rwy spacing

Q.# 17

On receiving the traffic I always looked at the nav display to see the traffic and to reaffirm in my mind the "escape bar" was right or left turn. When I got the "turn cimb" I always focused only on the primary flight display.
I feel the intruder aircraft should be displayed with a trend line to give the pilot an idea of where the intruder is going.

Part 4.   10 NM range 2500 ft. rwy spacing

Q.#11

Needs to be louder

Q.#17

The smaller scale, of course, gave more information on the intruder and his/her path; however, the larger scale was adequate. On the larger scale, I could not look at the intruder long enough to get a trend, so a trend line on the intruder would be helpful.

Part 5. The Simulator
Q.#13
We were IMC
Q.#16
Didn't even notice it.
Part 6. Miscellaneous
Free Space comment:
I think Flight command guidance is in order, since in glass cockpit aircraft all maneuvers like windshear, go around, stall recovery, you are provided guidance.

<u>Pilot #2</u>
Part 1 2 NM range 3400 ft rwy spacing
Q.#17 There could be a situation when the intruder has passed in front or behind, therefore changing sides. Then if he decides to get back on course could intrude again from other side causing your escape bug to be invalid.
Q.#18
The yellow "traffic" flashes right on top of your display information for the ILS tracking - a slight nuisance - when only a caution.
Part 2 2 NM range 2500 ft rwy spacing
Q.# 17
When traffic visually crossed in front of nose - it felt natural that if he got too close to break up and behind him - away from bug.
Q.# 18
Just as previously noted - "Traffic" caution. (See Q.#18 Part 1)
Part 3 10 NM range 3400 ft. rwy spacing
Free space comment:
I didn't realize how much I used the better map scale yesterday (2 NM range) -- it was a great help.

part 4
Q.# 16
Didn't always agree in that escape bug was not flexible under some unusual circumstances as previously discussed.
Part 6. Miscellaneous
In space for additional comments:
Other than items previously mentioned, the localizer/side stick seemed a bit too sensitive to minor inputs, but the again, I been flying "Collins wedges" and not these "Sperry X bars" lately. So I'm used to flying the wedge and not the "dot." So I probably needed a bit more of a learning curve.
Anyway, I felt the actual flying was a bit too sensitive.

<u>Pilot #3</u>
Part 1
Q.# 5, 6, 7, and 8
IMC
Q.# 18
Need guidance info in PFD. You are making an emergency maneuver, keep it simple and give guidance on one display. 45 degrees is too quick. You are asking for full control deflection and

a missed approach, but you want to stop at 45 degrees. Maybe a heading (*line? word not clear)* 45 & 90 degrees (or heading guidance on the PFD).
This display was a little confusing. It appears that he is not turning, but maneuvering completely (*word not clear*). My briefing led me to expect that his projected course and position would come from his nose.

Sketch not included

Part 4
Q.# 3
With the 2.5 miles scale *(10 NM)* the PNF will be concerned about the traffic and this display is insufficient to alleviate his concern. The PF is too busy concentration on this PFD, but the PNF is not.
Q. # 4 With the 2.5 mile scale *(10 NM)* there is a possibility the pilot could turn the wrong way. The expanded view gives you good situational awareness of the position of the intruder. The 2.5 scale *(10 NM)* the situational awareness is reduced.
Q.# 5
Note: Check escape maneuver with a *low engine failure (italicized words not clear)* at the time of the escape resolution.
Q.# 17
Need direction of turn on PFD - large arrow would be good.
45 degrees of turn is too quick for this radical of maneuver

Part 4
Part 1 2 NM range 3400 ft rwy spacing
Q. 4*(The additional workload was: d. low)*
Comment: After I got used to it.
Q.# 18
3D (climb and or descend information)
part 2
Q.# 16
Turn Climb descent info be given on PFD.
Part 3
q.# 17
Change range presentation from 2.5 to 1.5 miles.
part 4
Q. # 16
I would have followed system but felt uncomfortable.
Q.17
Combine the upper and lower display into one large monitor.
Part 5
Q.# 8
I found the side stick controller fun.
Q.# 14. The out of the window scene was (e) highly favorable
comment: runway environment

Pilot 5

Part 1 2 NM range 3400 ft rwy spacing

Q.# 5,6,7,8

Because we were in IMC

Q.# 11 Computer voice “Climb, Turn” (response: Somewhat helpful)

Although still seemed to lag behind alphanumeric visual.

Q.# 13 (Response: occasionally)

Because it reiterated the direction of turn in my mind.

Q.# 14

Did not maneuver w/o and alert.

See #13 above for note.

Q.17 (Response: occasionally I would have broken off when no red was given)

If in VMC I would have felt differently about continuing after an aircraft passed in front of me.

Q.# 18 (Suggest modifications)

Repeat the turn direction indicator (currently escape bug) on the PFD.

Suggestions: (i) The word “Left” or “Right” above horizon on appropriate side of PFD.

(ii) Highlight the 30 deg. bank index which would additionally stress target bank angle.

(iii) Red shade right side of PFD? (A bit extreme perhaps)

Part 2

Q.# 4

Workload difference may be greater in (full workload) airplane.

Q.# 10

I was concentrating on the PFD already so I saw alert right away-- Aural alert seemed to have a slight lag.

Q.# 14

I was instructed not to maneuver without an alert.

Q.# 17 (Response: Occasionally I felt I would have broken off when no red alert was given)

Comment: If I could see intruder aircraft.

Q.# 18

Give loc *(localizer)* display at bottom of PFD greater bias and improve/increase loc warning, i.e. give better warning for approaching turn to loc (*capture, word not clear*).

Part 3

Q.# 5,6,7,8

IMC

Q.# 12

I responded to alert immediately. I exclusively (i.e. used only) alphanumeric and voice alerts for my response.

Q.# 13

Because I couldn’t tell with the 20NM display what the intruder path was.

Q.# 14

Same note as 13 above.

Q.# 16 (Response: Always agreed with the display and procedure)

Because we were IMC. If we had been in VMC I would have broken off when aircraft passed in front of us.

In space for additional comments:

Good use of time in sim.

Part 4

Q.# 4 (Response: Workload very high)
Comment: Due to the scale it took a lot of looking to get the info I wanted -- where is intruder? Where is he going?
Q.# 6 - 8
IMC -- If VMC I would look out during 6 and 8 only *(straight-in portion and evasion maneuver)*
Q.# 13
I couldn't discern that info from display. Would've liked to known intruder flight path prediction.
Q.# 14
Maneuver based solely on alphanumeric and voice alerts.
Q.# 15
Nature of maneuver based on escape bug <u>only</u> (no intruder).
Q.# 16 (Response: Occasionally would have broken off when no red alert given)
Traffic passing in front of us in VMC (if traffic in sight)
Q.# 17 (Suggest mods)
Go back to expanded display! (2 NM range) The extra info provided helps by (i) reaffirming maneuver turn direction, (ii) enabling me to predict a level two alert, vs. react to it.

In space for additional comments:
I found that the 20NM display range (wide field view) was inadequate to predict intruder's movement. No flight path predictor and the bunched display made predicting intruder' movement essentially *(im)*possible because I didn't want to spend as much time off the PFD, on the ND, as would be required to figure out where intruder is headed. And that's nice to know for reasons given in 17 above.

Part 5 -- The Simulator
Q.# 2 (Response: Simulator biased my performance/ slightly improved)
Comment: due somewhat to side stick controller vs. std yoke config.
Q.# 13
Because its nice to see a 'picture' of what you're doing while w/o visuals
Part 6 -- Miscellaneous
Q.# 6
I didn't really notice this retraction. I'd prefer the flt. director command bars to command a climb and turn to evade.
Q.# 8
No one I know likes to go belly up to another aircraft, its favorable to a collision.
Q.# 10
It's essential to have a plan <u>before</u> you need it.
Q.# 15
You wouldn't know where he was going relative to your aircraft. Who cares where he is over the ground as long as I'm not over the same ground at the same time.

<u>Pilot 6</u>
Part 1 2 NM range 3400 ft rwy spacing
Q.# 18
Make heading set marker more visible by making it magenta, or flashing magenta when a climb/turn alert is given.
In space for additional comments

Move “Traffic” alert display away from flight director bars approx. 1/2 inch. As it is, the display is too (drowned, *word not clear*) in flight guidance info and is distracting.
Pilot not flying should have 1/2 mile scale (2 NM) displayed and relay pertinent info to pilot flying.
Put distance to active waypoint on PFD, below active waypoint.
Part 3
Q.# 17
Display on ND not large enough to determine intentions of other aircraft or any trend info of intruder aircraft.
Part 4
Q.# 16
I felt the safest course of action was to follow the alert under all circumstances. No time for judgments or evaluations.
Q.# 17
There should be a 15 degree pitch bar marked as such. 15 degrees is standard for an escape maneuver. I found myself searching for the 15 degree pitch line. There should also be some indication as to direction of (required, *unclear word*) turn and heading indication of the PFD. Under circumstance the would require this system, namely IFR conditions, it would be essential that it be certified for autopilot use only. This would necessitate the incorporation of a flight director for the escape maneuver. Pilots who fly EFIS aircraft do so with a flight director in all phases of flight. Not having one during the escape only adds to the stress of the maneuver.

The most important thing would be to <u>insure</u> the pilot turns the right direction. Left or Right. This should be safeguarded in some type of automation and preset prior to initiating the approach.

Consider moving the ND to sit directly to the right of the PFD. Eye movements left and right, and not up and down would provide for an easier scan.

<u>Pilot 7</u>
Part 2
Q.# 17 (Response b. Occasionally I felt I would have broken off when no red alert was given.)
Comment: Airline procedures would have most crews initiating a separate maneuver or go around earlier than the equipment called for it -- Just to be completely safe in IMC. When VMC and traffic in sight however, I believe I would continue approach and not rely on equipment.
P.S. I related a close approach path problem at SFO to the researcher that I believe this equipment would have helped with.
Part 3
Q.# 16
The situation display help confirm guidance
Q.# 17
I wanted to zoom into larger expanded scale as target got closer -- to verify geometry.

In the space for additional comments:
VSI - too hard to utilize.
Intruder symbols should be same as TCAS - some confusion initially

Needed ability to expand NAV display to assist in joining localizer - at present I had to rely of flight director.
Part 4
Q.# 17
Heading in degrees on PDI below the 10 degree tick marker.

Pilot 8
Part 1 2 NM range 3400 ft rwy spacing
Q.# 5-8
Out of window views - I looked enough to confirm IMC too thick to see through.
Q.# 10
It would be much more effective to make FD turn red and command action
Q.# 11 Voice seems too late

Q# 12-14
Once a level 2 alert is given (traffic) all I looked for was a turn climb. I completely ignored the NAV display. Reason: Goal for experiment is reaction time. I know which way to go -- All I need is the command. Real world, though, I'd look at NAV Display and continually evaluate geometry. This would change my answers to 12-14.
Bottom line - experiment assumptions drove my responses.

In space for additional comments:
At first, in the expanded range, the fixes moved by uncomfortably fast. I didn't like it. After a few runs, I was used to it and liked it. But, I would like to know about the next fix off screen - something like traffic is displayed. How about an own ship 2/3 down display (*as opposed to own ship centered in the ND*). I understand why now, it's okay.

On practice I intentionally flew 1 1/4 dots off and got "Localizer" on the ADI. I think it still said "localizer" instead of "Traffic" when the conflict appeared (HSI was normal).

Once again -- I strongly suggest paralleling TCAS. This means an aural "Traffic - Traffic" call and aural "Clear of conflict" call.

Make the "turn climb" voice more urgent and quicker. Include a direction.

When traffic became a factor, I wanted better CRS and GS info on the HSI and I wanted traffic info on the ADI. Keep it graphical if possible.

I'd like to see some predicting device on the intruder's display that would give me a heads up on when I'll get a "Turn - Climb." For instance, if you use time to collision (another TCAS algorithm) you might have a mark at the 20 second point:

Consider auto range switch with localizer capture.

Consider procedurally for future

- Expand range on final
- Call traffic active on screen
- Keep airplanes on same frequencies for better situational awareness

Call left or right escape when established on final or when bug.

Note: “ Traffic” seems to appear on Flt Dispay (0.4 -0.5 sec?) before the graphics on NAV Display. (That’s better than reverse!)

Put some version of the escape bug on ADI.

As day wears on, reactions seem to slow. Later ones more realistic.

I like tgt *(target)* on screen at proper azimuth! but how can I tell if he’s off scope or on course?

I believe TCAS does an open diamond. Do we? Why not? (*As opposed to a filled diamond.*)

Pilot 8, continued.
Part 2
In space for additional comments:
I found myself more and more evaluating threat potential. That’s good, but I may have spent too much time on the nav display. Any extra tools for helping determine when a level 2 warning goes level 3 would help me not look so long and think so much about evaluating potential threat.

Once I get a level 2 warning and a path prediction for an intruder, I’d like to see it stay. When he goes back white, I’d like to see the path stay, but turn white, at least for a while. This is especially true for intruders crossing my flight path.

I’d really like the option to escape toward the intruder under some circumstances. If the flight director gives me direction for escape -- this would be easy. Escape bug could flop sides when given geometry proved this solution (and it should be annunciated on the ADI).

Part 3
Q.# 16
I wanted to see more detail. I wanted to see his flight path and closure rate.
Q.# 2
I’d split this question up - analyze for loc capture to FAF
FAF to 1000’
100’ to 500’
500’ to rwy
or something similar.

Q.# 5
I assumed IMC. I’d look out a lot more if VFM or intermittent/marginal VMC
Q.# 8
Again - assumed IMC. I focused, post evasion, on the ND separation.
Q.# 9
There seemed to be a lag (0.2 -0.5 sec?) between visual and aural warning. This is bad, I think, visual warning appears first.
Q.# 13
Definition of escape maneuver precluded analyzing intruder’s position... so, apart from knowing which direction he was approaching from, the experiment seemed to force a “never” answer.

Q.# 14
See above. There were times I'd like to have maneuvered -- especially a speed adjustment, but thought that was out of the allowable actions of the experiment.
Q.# 15
See above # 13
Improvements to consider?

Move F/D bars to command escape
Make aural warning simultaneous with visual
Make an aural "traffic" call (like TCAS)
Flash "Traffic" -- it's not really as noticeable in yellow/amber steady as it should be.
Multiple lines on the ND get mixed together. Maybe prioritize some.
How about a projected flight path for intruder after a "Traffic" warning?
Annunciate the appearance of the escape bug better. (tone? flash it? something on the ADI)

Part 4, Pilot 8 continued.
Q.# 17
At 2500' -- the need for an expanded display and intruder vector information is even more critical. Put the intruder on the ADI if he passes in front -- include Altitude -- For wake turbulence avoidance?

In space for additional comments:
See previous comments -- all still apply
Q.# 15
If the question means did the display help to determine the nature of the maneuver I was about to perform, the answer is no -- because it was a canned no-brainer procedure. If the question means did the display help me determine the nature of the post maneuver geometry -- the answer is yes -- every time!

Other notes:
-- I was more "nervous" at 2500" . Tended to look outside more hoping for a glimpse thru the fog.
-- Below 1000' avoidance maneuver made a much bigger psychological impression. Didn't like tracking TFC + GS + LOC. I tended to cheat away from traffic here and elsewhere.
-- I want to look outside even more, but I'm afraid I'll miss the cue and add to my reaction time.
Part 5 -- The Simulator , Pilot 8 continued
Q.# 1-3
Just the fact that this is a repetitive part task simulator enhances my response. Making reaction time a goal further affects how I did business.
Q.# 9
Hardest part about side stick controller was using left handed.

Part 6 -- Miscellaneous
Q.# 1 The Flight path marker made all tracking very easy. Runway symbology is great! Didn't even notice localizer sensitivity differences. I ignored the command bars after a while.
Q.# 5-6
Break-off bug is helpful -- given the required maneuver. But, it and command bars ought to be dynamic - responding to geometry, in my opinion.
Q.# 9

Real world, no one would escape that violently.
Q.# 10
Computer should select and command a proper escape. Pilot need only react.

I loved intruder flight path. Keep it and use it more !!! (See previous comments)

<u>Pilot 9</u>

Part 1 2 NM range 3400 ft rwy spacing

Q.# 17
Several times traffic passed in front of me on final -- I would have gone around but system didn't tell me to.
Q.# 18 Suggest mods.
1. Accentuate glideslope in contrast and size.
2. Shorten length of white predicted a/c path line in approach phase, okay in localizer intercept. It is distracting as it "waves" back and forth during localizer track.
3. Vertical speed, as displayed, is useless.
4. Eliminate a/c impact point and runway symbol until below 1000' AGL on final.
Q.# 11
System voice should say "turn left/right and climb"
Part 2
Q.# 5-8
In IMC conditions pilot should not be looking out of windows for anything but ice!
Q.# 9
I really don't know without seeing the traffic -- we didn't have near miss so that's okay!
Q.# 12
Confirm turn direction in turn.
Q.# 13
If I was given the option of choosing path it might be; right now my only options are to fly loc and g/s and escape maneuver when alerted to do so.
Q.# 14
See #13 above
Q.# 15
See # 13 above
Part 4
Q.# 3
The "10 mile mode" of navigation display of traffic provided little useful information (only that there is traffic on right/left side, and relative position to me. It is useless to judge closure, separation or trend -- in fact it distracts because it draws attention and causes pilot to dwell on it while not being readily understandable.
Q.# 5,6,7,8
Approaches were in IMC conditions, therefore I did not look out windows.
Q.# 11
Voice should say "Left/right turn, Climb" -- Direction first.
Q.# 16
The 10 mile display is even more disconcerting and would cause me to go around because I can't really tell what the intruder is doing. With the 2 mile display I could tell more about the situation.

Note on escape bug: When it appears on nav. display it should blink twice (off/on) the on steady to catch my attention.
Q.# 12
I tried to fix in my mind what I was going to do (direction of turn) prior to alert.
Q.# 13,14,15
It really is not my task to avoid collision by judging intruder position -- I just fly escape when alerted (and hope for best!)
Q.# 17
Situation glideslope indicator should have more contrast. Inhibit impact point (*display*) until less than 1000' on final.
Part 6 -- The Simulator
Q.# 5
Should blink twice after added to display.
Q.# 8
Should be standard go around to specific altitude -- (use, *word not clear*) 15 degrees nose up.
Q.# 11
If either you or the intruder is one dot off loc, something is amiss.
Q.# It has to be relative to me!

<u>Pilot 10</u>
Part 1 2 NM range 3400 ft rwy spacing
Q.# 3
Expanded mode too expanded -- traffic off screen pops up and becomes a factor.
Q.# 6
Only with TCAS safe front crossing
Q.# 10
Please direction (Lt or Rt)
Q.# 13
Prior to emergency alert
Q.# 14
after alert, I moved immediately
Q.# 16
Unknown if I could climb into intruder with present system.
Q.# 17
No, too little info to argue command
Q.# 18
Aural tone/chime for 1st level alert

In space for additional comments:
Put course guidance in PFD for escape so pilot can focus on one instrument during critical maneuvers. Tie command bars to course, altitude, pitch, and bank desired.

Part 2
Q.# 2
If blank, more if traffic in view
Q.# 6
response: never look -- comment: IMC, except predicted cross in front.
Q.# 9 (Was adequate time allowed)

But what if I had not seen this for 22 years.
Q.# 10
Lt turn, climb, etc.
Q.# 11
Give direction
Q.# 13
Prior to intruder alert
Q.# 14
Assumed a go was a must
Q.# 15
Prior to the alert
Q.# 17
Would like the option to reset system if desired not to break out (i.e., VFR or broken conditions. Would like symbol for other a/c direction. (Hand sketch shows symbol for second aircraft rotated with its heading.)

Pilot 10, continued
Part 3
Q.# 4
Scale not expanded enough
Q.# 6
IMC, unless suspected frontal crossing
Q.# 9
Given I was "primed" for it
Q.# 13
Prior to the alert -- situation awareness
Q.# 14
Not after the alert
Q.# 15
Same move every time
Q.# 17
Have candy stripe bug a rectangle w/o a notch as I understand we are expected to turn at least 45 degrees. Possibly a smaller 10-20 degrees arc of green beyond the bug to indicate an expected roll out range -- again helpful if on the PFD.
I miss expanded view.

Part 4
Q.# 3
Expanded
Q.# 4
Unexpanded harder to interpret quickly
Q.# 12
Except check candy stripe bug if unsure.
Q.# 13
Prior to intrusion
Q.# 15
Before the intrusion
Q.# 16

If I knew an aircraft was passing in front, I would want to avoid vortex even if no impact conflict. Q.# 17
Too much on PDF [... *unclear words...then*,]goal post (white)]

In space for additional comments:
Would like a single chime when “Traffic” first illuminated – esp. VFR conditions.
Pilot 10, continued
Part 5 -- The Simulator
Q.# 2
No motion, hand controller seems stiff
Q.# 10
Loc intercept and roll out tough
Q.# 14
N/A
Part 6
Q.# 6 (retracting command bars at alert)
Might help to have them.
Q.# 7
Easy to over bank with no motion
Q.# 9 (responded escape maneuver was somewhat objectionable)
Comment: Vertigo
Q.# 11
aural chime
Q.# 15
Don’t know

In space for additional comments:
Would like to try intruder w/ ground track vs. relative track.

<u>Pilot 11</u>
Part 1
Q.# 17
Only if in IMC
Q.# 18 (Suggest Mods)
Excellent as is!
Part 2
Q.# 17
In IMC, once I received an alert I would still execute the escape maneuver even with the expanded information.

In space for additional comments:
The expanded display is extremely important, it allows the pilot to track the intruder display much more accurately and closely. The negative aspect of this is that it increases pilot workload moderately due to the extra emphasis placed on observing the intruder. My aircraft control suffered much more when I had a traffic alert than while in the nonexpanded display. I also found I relied more on the audible “Turn Climb” than the visual “Turn Climb” on the PFD, which is just the opposite from yesterday.
Part 3

Q.# 17 (Suggest mods)
Providing a wind arrow and ground speed readout in the PFD would be nice, but would not actually aid in the performance of the escape maneuver.
In space for additional comments:
I am very impressed with the potential for the implementation of this system.
Part 4
Q.# 16 (response: Always agreed with the display and procedure)
Comment: If in IMC I fell you have to execute the escape maneuver! If VMC and the target was in sight, I could have evaluated the necessity of the escape a little more.
Q.# 17 (Suggest Mods)
Excellent displays and procedures, the only other helpful information would possibly be a trend "worm" on the target while in the 10 mile scale.
In space for additional comments:
Overall, I am impressed with this new technology, I think it would be of immense value at certain airports especially while flying in IMC.
In space for additional comments:
Overall an excellent idea with grand potential. From the viewpoint of flight deck personnel, I think most pilots will find it a favorable system.

Pilot 12
Part 1
Q.# 16
This relative path is very helpful in knowing the relative position of the possible intruder and in anticipating any possible maneuver.
Q.# 18 (Suggest mods)
The intruder path display is the most desirable presentation because it not only gives you relative position but allows you to anticipate any possible problems.
Part 2
Q.# 18 (Suggest mods)
Brighten and move the heading bug to 60 degrees -- This is emergency procedure to avoid a midair collision.
In space for additional comments:
The intruder path display is important for two major reasons:
1. It gives you better relative position.
2. It allows possible options to consider instead of aborting the approach such (as) increasing speed slightly, move to parallel the localizer momentarily or climbing/descending off glide path slightly.
Part 3
Q.# 3 (response: ND traffic display somewhat helpful)
To determine the other aircraft's relative position.
Q.# 15
The seriousness of avoiding a possible midair made the evasive maneuver a mechanically structured emergency procedure.
Q.# 16
The seriousness of this situation necessitates a maneuver that assures separation -- immediately! from the other aircraft.
Q.# 17 (Suggest mods)

Since the heading bug is such a crucial part of not only heading but direction during the maneuver, it should be a very bright and obvious color -- Orange/pink/red. etc.
In space for additional comments:
It would be very helpful if the glideslope indicator was also more visible -- brighter in color.
Part 6 -- Miscellaneous
Q.# 14 (relative path display)
I support this feature 100 percent.

Pilot 13
Part 1
Q.# 18 (Suggest mods)
I would like to compare (*reaction*) time with yoke and (*side*) stick
Pilot 14
Part 2
Q.# 17
Wake turbulence needs to be considered.
Q.# 18
Traffic on PFD could be useful.
More info on other aircraft could be useful to PNF.
In space for additional comments:
Much more interaction between crew members is essential -- ... more information presented to the PNF could help in keeping the PF updated on traffic information.
Part 3
Q.# 17 (Suggest mods)
In hand flying it was difficult to use the ND. The FD needs to be brighter or higher contrast.
The traffic display needs to be expanded.
In space for additional comments:
In hand flying it may be better to have the traffic also displayed on the PFD.
It may be better to have a single cue FD for those who fly it all the time.
Part 4
Q.# 17 (Suggest mods)
Same as before. Need more resolution on ND.
Part 6 -- Miscellaneous
Q.# 6
Would have been better to have FD display the maneuver.
In space for additional comments:
Excellent start to discovering the best presentation for parallel approaches.
Should probably try with closer spacing.
Definitely need a 2 person crew totally involved in the procedure.
Should experiment with more information of both displays.

Pilot 15
Part 1
Q.# 18 (Suggest mods)
Same as 2500 ft. survey, except escape heading bug should flash for a period when presented and also during the alert. Should also be bolder presentation, i.e. bright red.
Part 2
Q.# 17

Had one where no conflict was going to occur, but followed command.
Q.# 18 (Suggest mods)
Explode view automatically if pilot forgets at marker, or with traffic warning.
Part 3
Q.# 12
For traffic “Traffic” always
Part 4
Q.# 17
In my B-757 any active track on the map is an active LNAV track.
Maybe the parallel runway centerline could be dashed.
Compared to the exploded display, information is scant. A ‘Turn Climb is much harder to anticipate.
Part 5 -- The Simulator
Q.# 16 (Eye tracking equipment)
Did not notice

Pilot 16
Part 1
Q.# 18 (Suggested mods)
I would like better vertical speed info. I was concentrating so much on altitude I frequently missed vertical speed with a quick glance. Thus I would sometimes call “pos rate gear up” when in fact I was still sinking. If I took extra time to locate and process vertical speed then I frequently over banked the aircraft due to the aggressive aileron required to escape and my extended look away from attitude.

Too many lines when on loc. I don’t see a need for my own aircraft trend line or an FMC line. Just LOC centerline and my ground track would suffice. I don’t have time to see and/ process info if there is too much of it. I love zoom in and the 2 mile scale, especially when the two aircraft are in or near the abeam position.
Part 2
Q.# 17
When an amber traffic is shown with the other aircraft’s path passing in front of mine, I would like to go missed approach and return for another without having to perform the abrupt escape maneuver.
In space for additional comments:
I was surprised at how little deviation by either aircraft close to the airport would trigger a traffic warning and /or escape turn/climb.
Part 3
Q.# 17 (Suggest mods)
I want to zoom in closer i.e. 5 mile scale when I feel other traffic intrudes into my comfort zone and certainly when I get a yellow traffic display.
In space for additional comments:
I never looked out the window before, during, or after and alert in the clouds because I assumed weather would prevent seeing other aircraft. Would look if not IMC.

I did find myself looking more at potential conflicting traffic as I became more comfortable with the cockpit instruments and the cross check became more efficient.
Part 4

Q.# 17
I found that the flight number, airline designator info of the ND added to clutter and gave me no useful info. I also found the small airplane symbol on the attitude indicator to be confusing. It seemed to contradict raw data at times.

In space for additional comments:
I never looked out of the window prior to and escape maneuver or during that maneuver because I was in the clouds and didn't feel I would see anything. That probably would be the job of the pilot not flying anyway.

I do like the alert feature because it gives you notice to prepare for possible escape. When I get an alert it would be helpful to zoom in and go to a smaller scale, i.e., 5 mile map to help evaluate the conflicting traffic situation.
Part 5 -- The Simulator
Q.# 16
Never noticed it (*the eye tracking equipment*) during any test runs, forgot it was there.

In space for additional comments:
Concerning the break off bug, not only did I like the stripes, but also the size of the bug. Makes it easy to locate in a hurry.

I wanted to see stronger crosswinds and to have the crosswind component vary with altitude as in the real world. This would have created more difficulty in staying on the localizer.

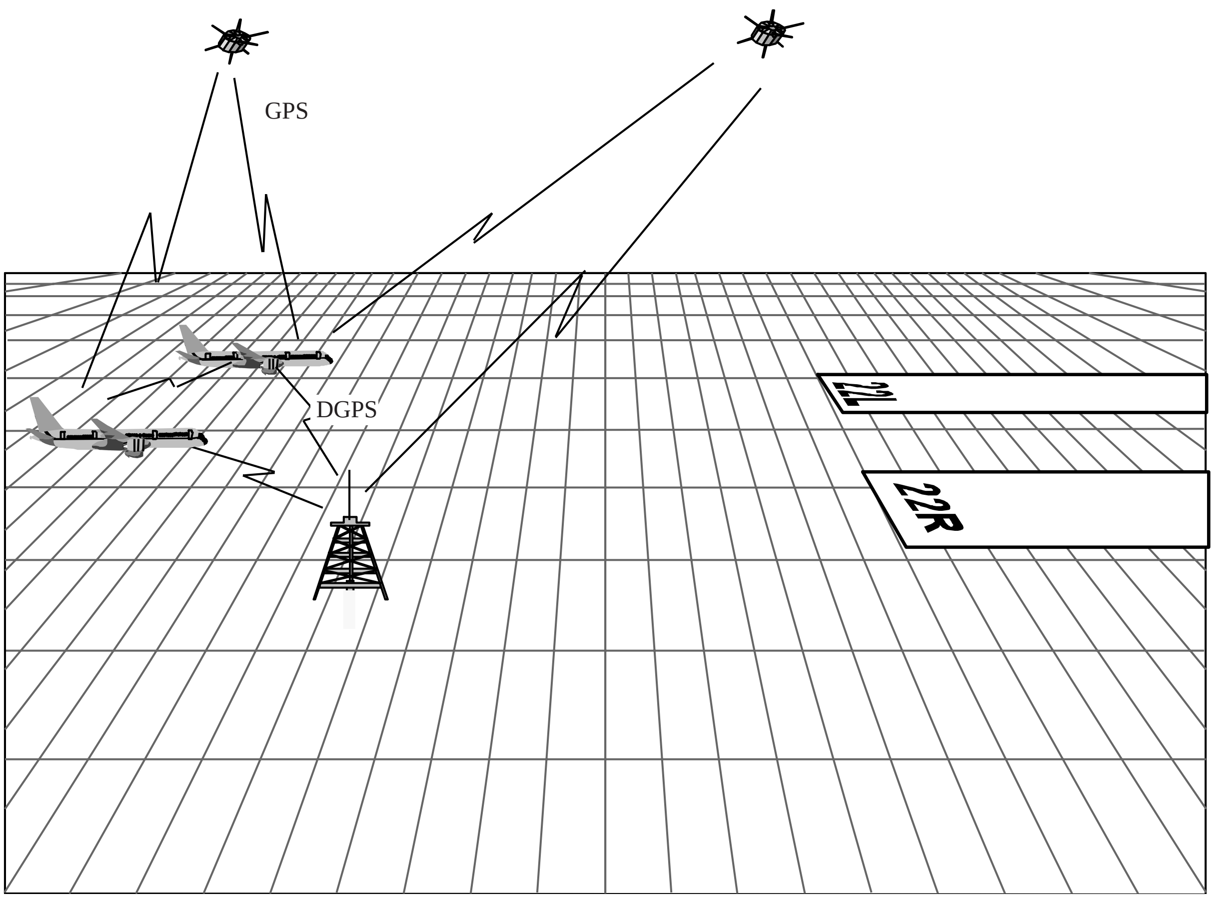


Figure 1. AILS parallel approach concept.

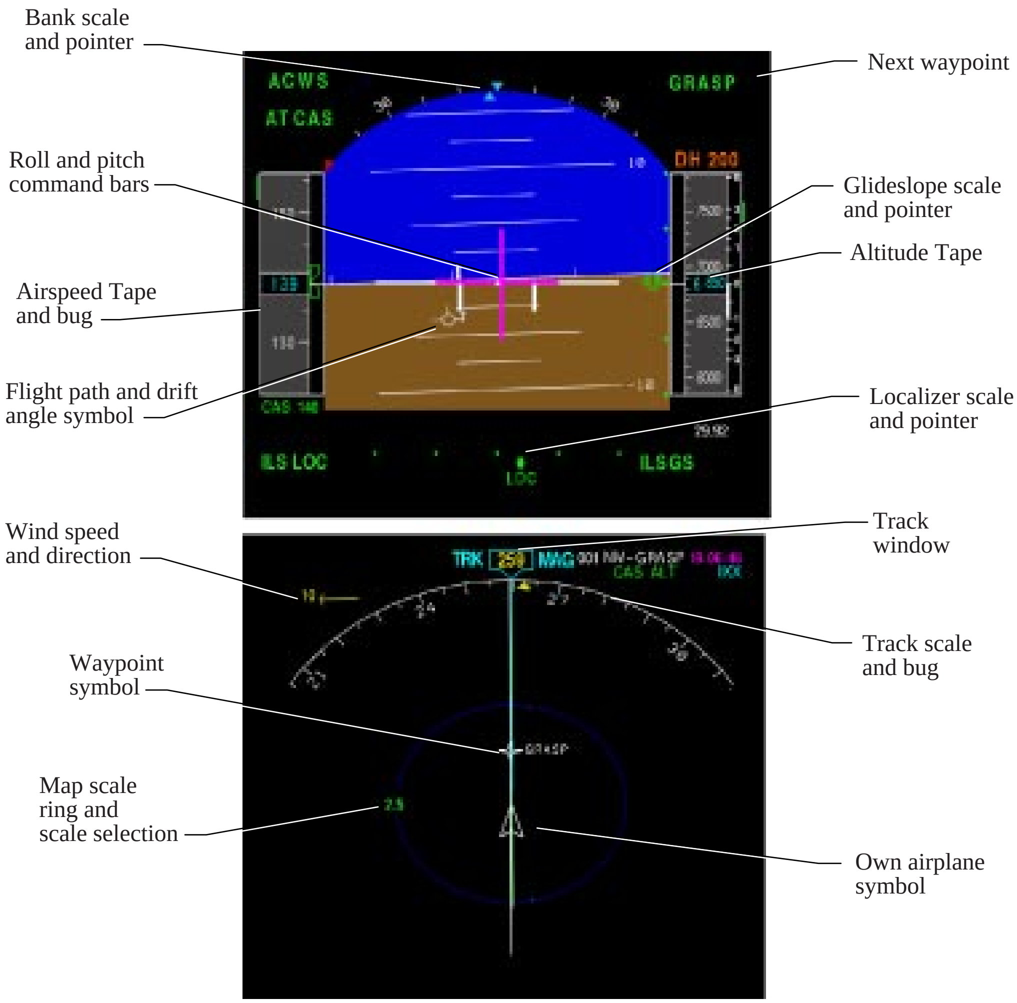


Figure 2. The PFD and ND without modifications.

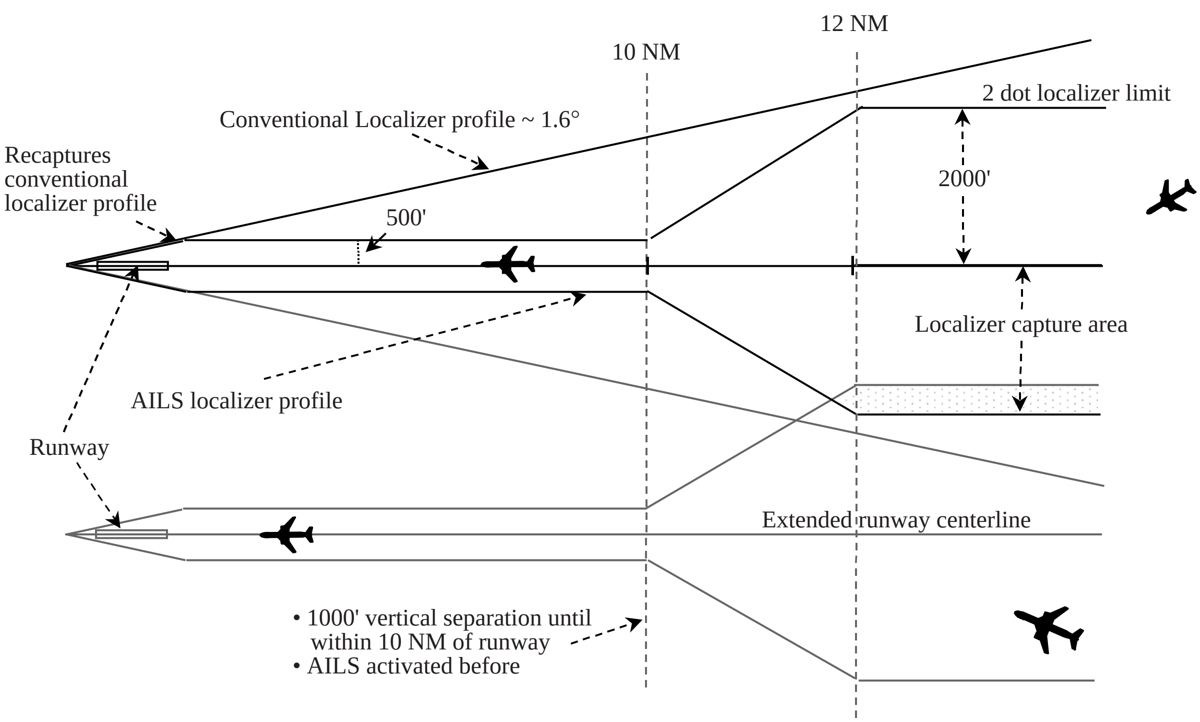


Figure 3. Modified lateral path constraints based on DGPS (Plan view of approach airspace).

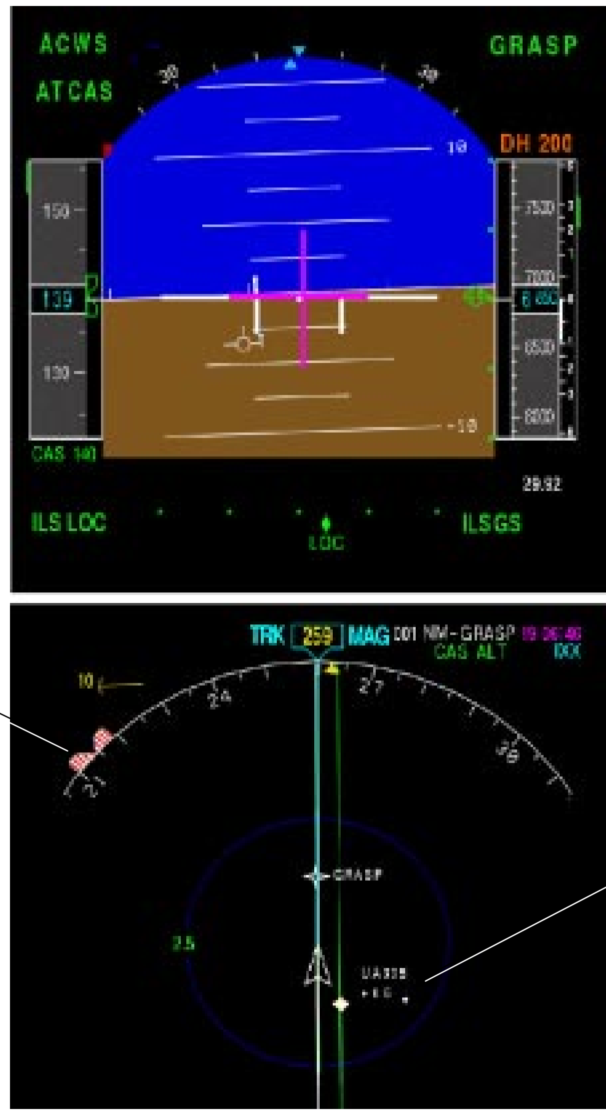


Figure 4. Example PFD and ND displays in the nominal AILS approach condition with no alerts.

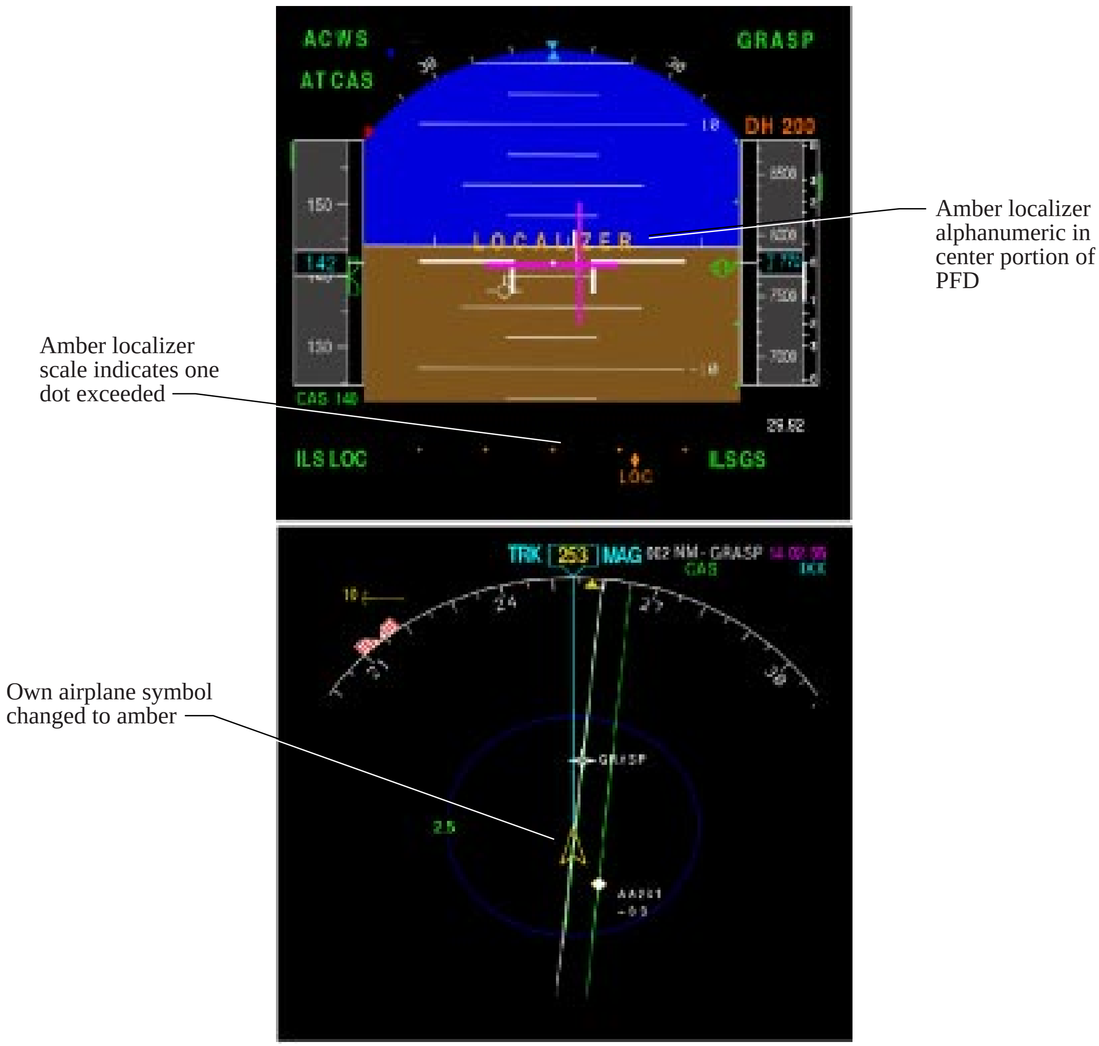


Figure 5. Example PFD and ND with level-two localizer deviation alert.

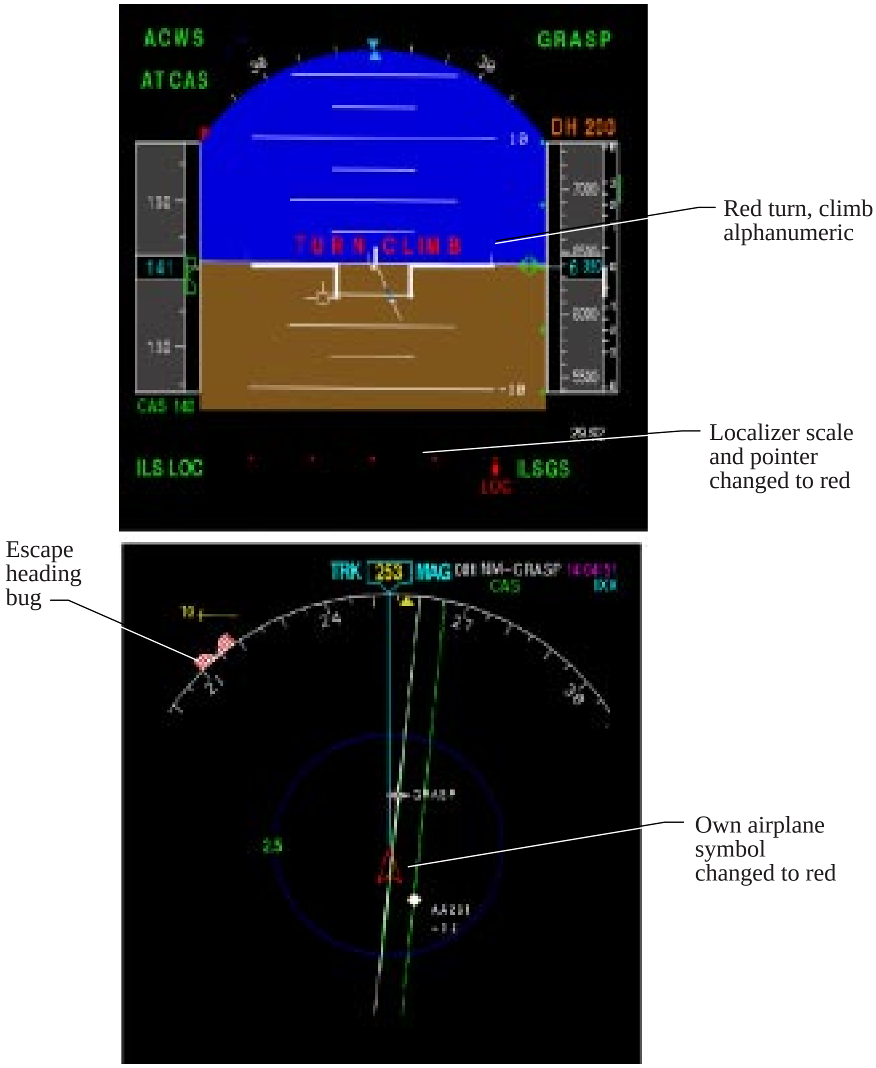


Figure 6. Level-two localizer deviation shown in the PFD and ND.

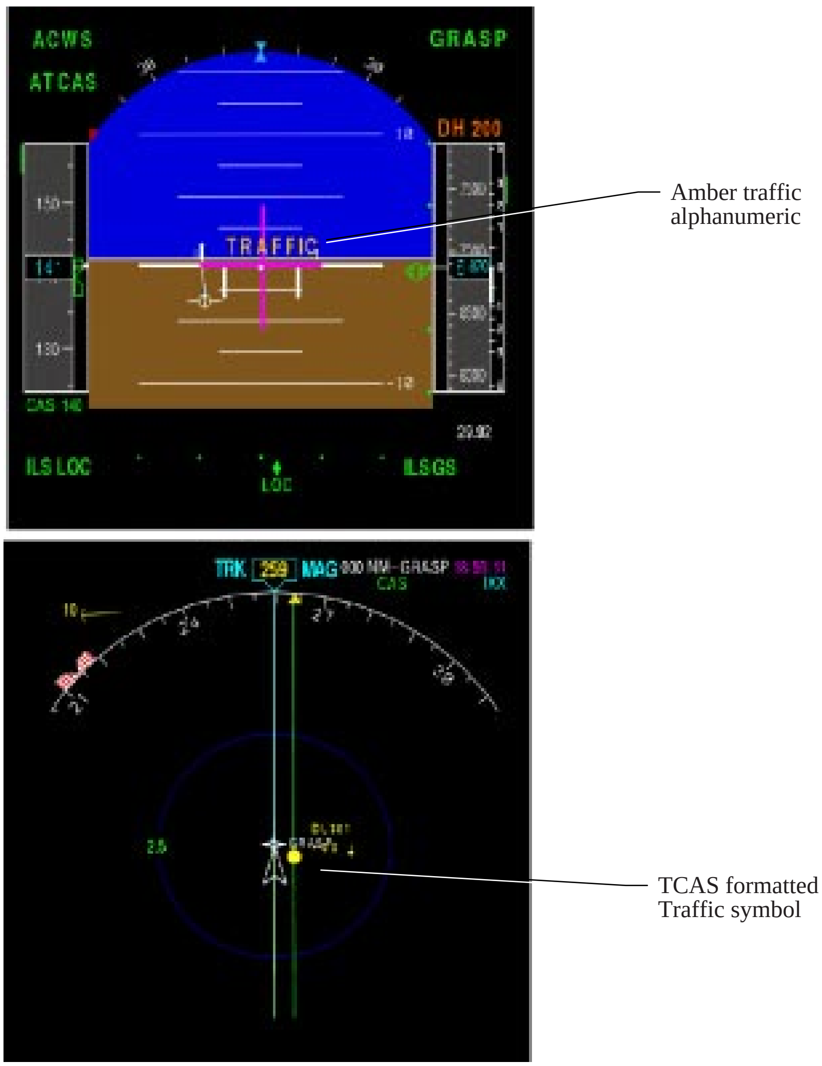


Figure 7. Example level-two traffic alert presented on the PFD and ND.

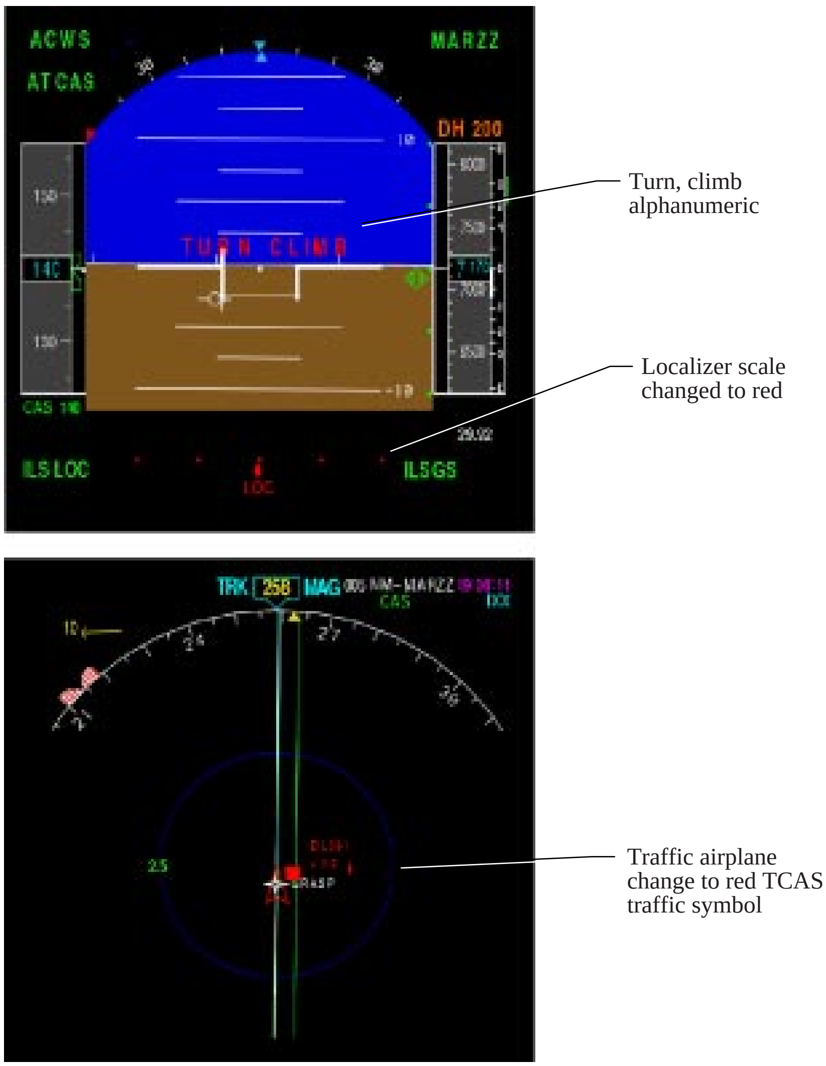
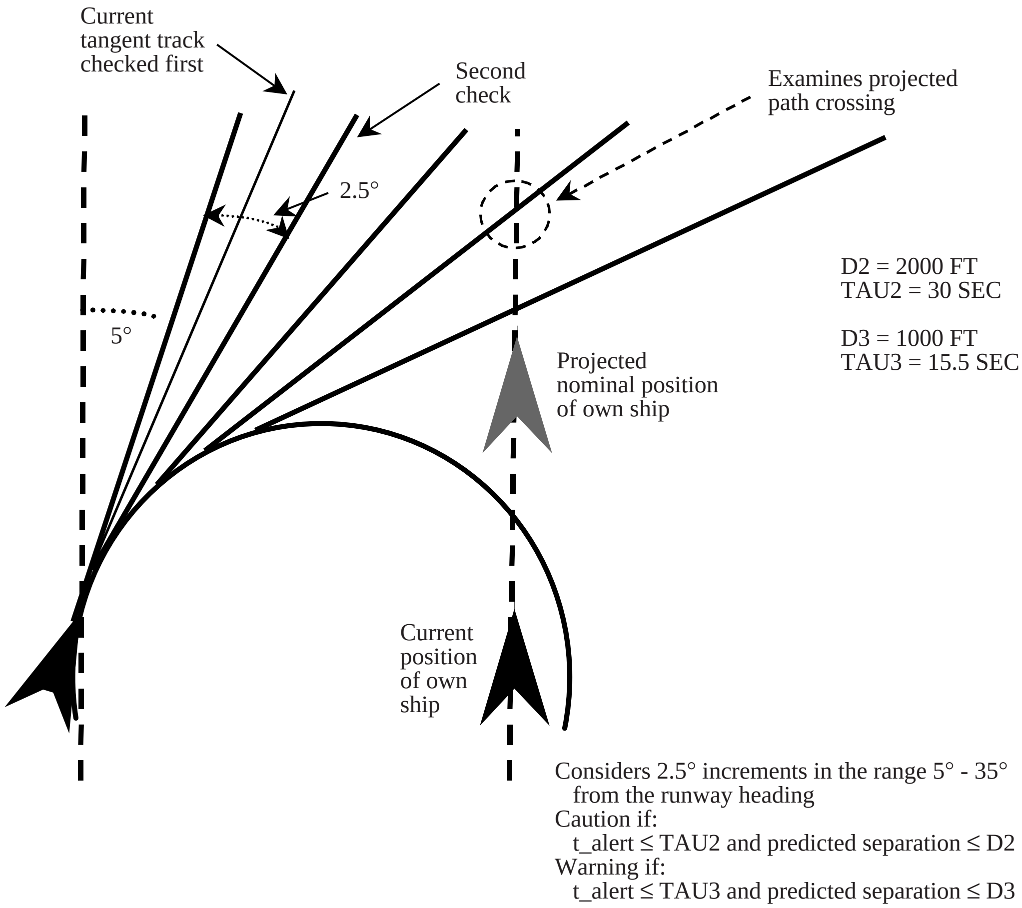
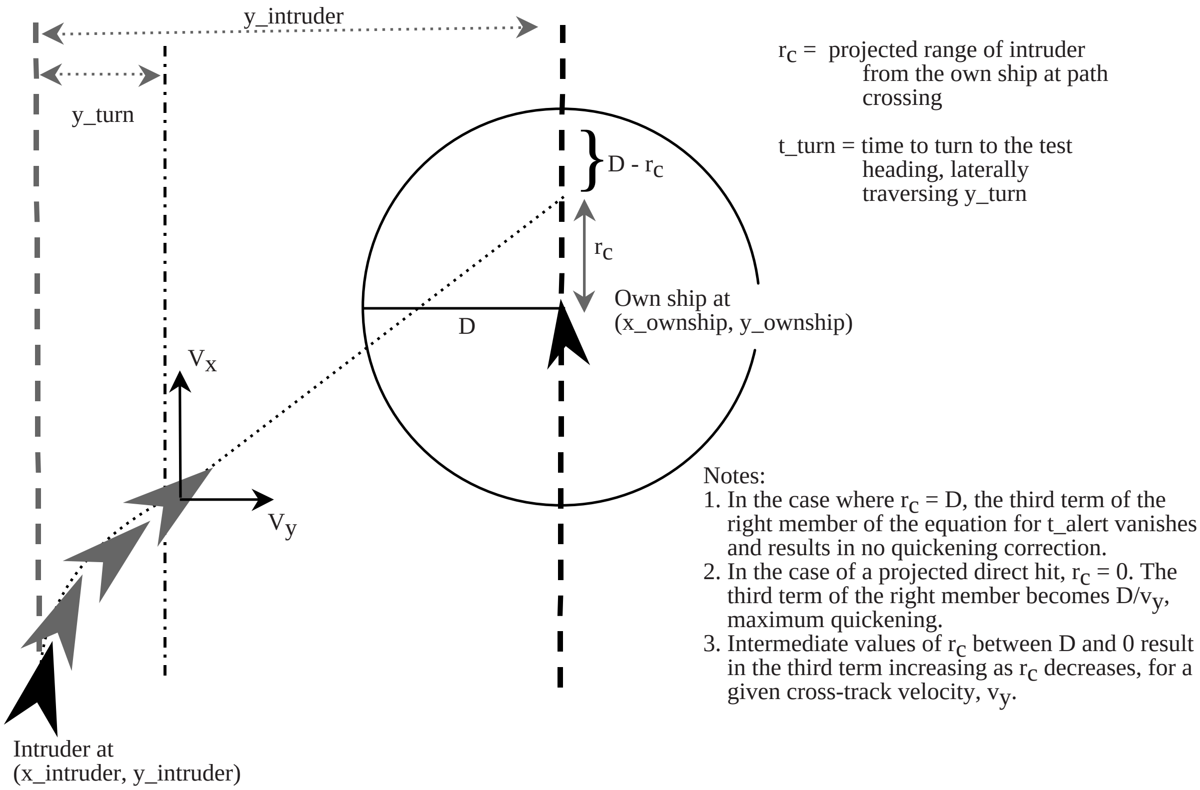


Figure 8. Example level-three traffic alert. Mandatory break-off using the escape maneuver (accompanied by aural “Turn, climb, ...”).



(a) Checks the relative state of the two airplanes at 2.5° heading increments.

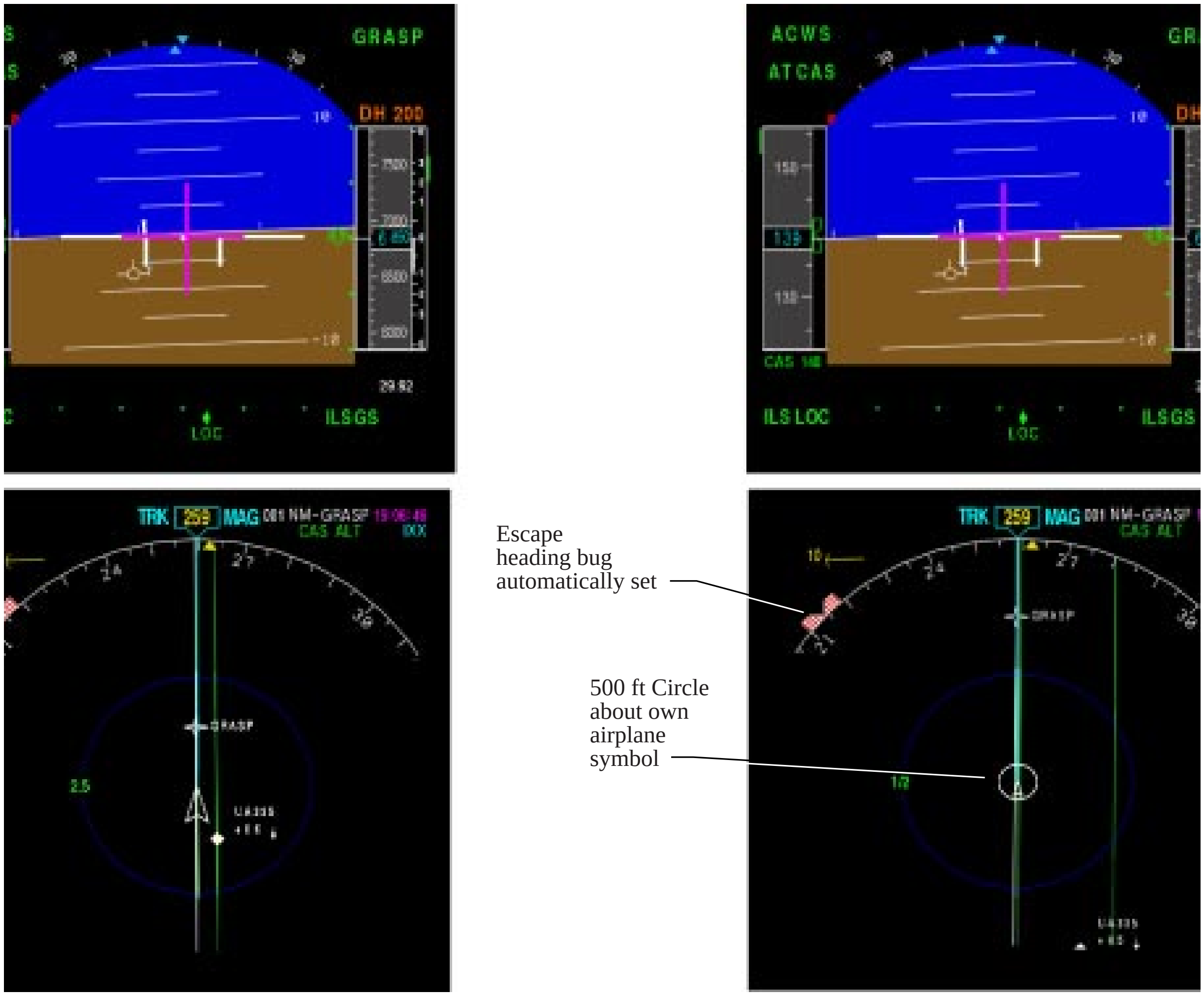
Figure 9. Segmented alerting criterion.



$$t\_alert = t\_turn + \{[(y\_intruder - y\_turn) - y\_ownship] / v_y\} - [(D - r_c) / v_y]$$

(b) Alert time (t_alert) computation.

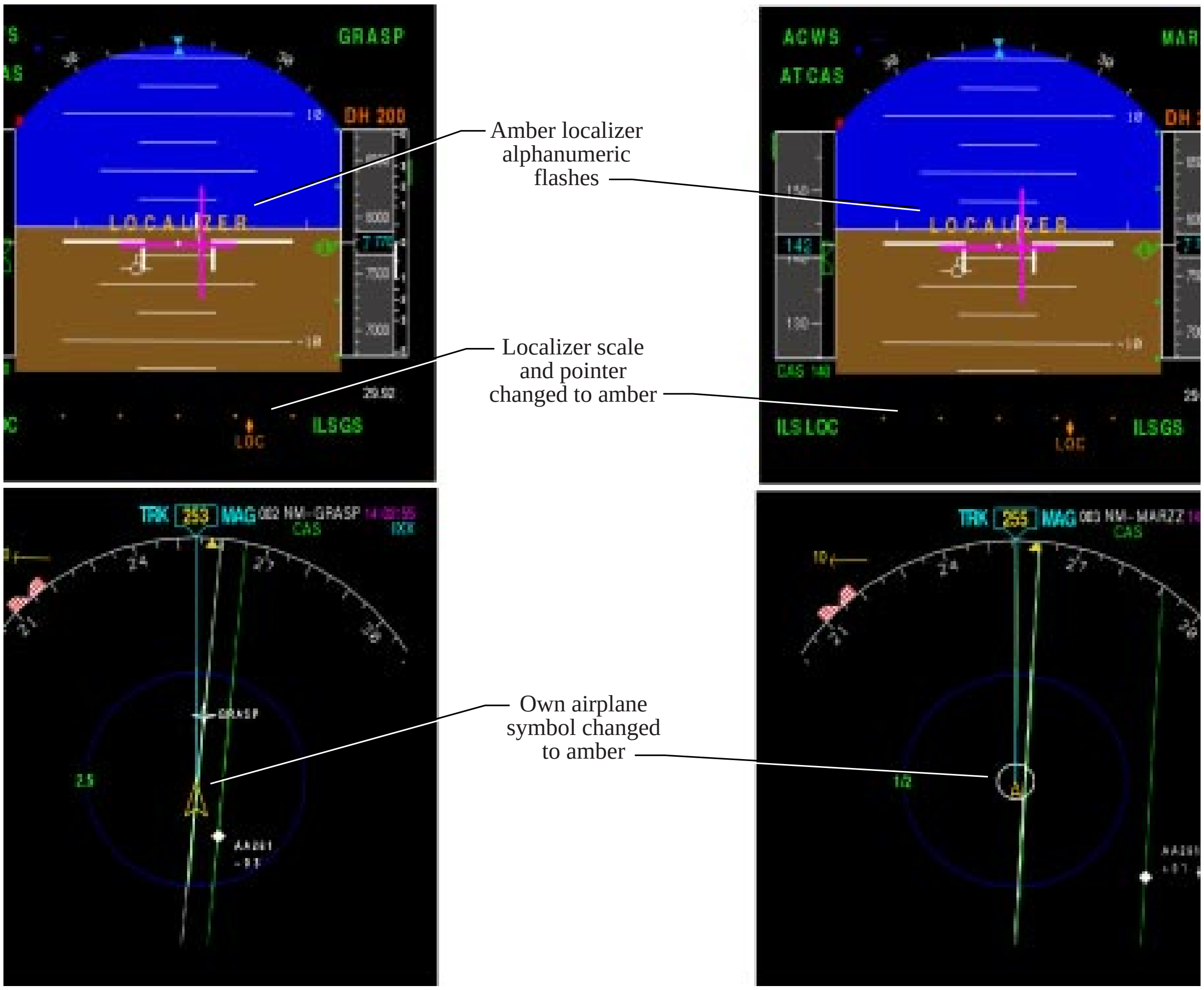
Figure 9. Concluded.



(a) Modified conventional display.

(b) Enhanced display.

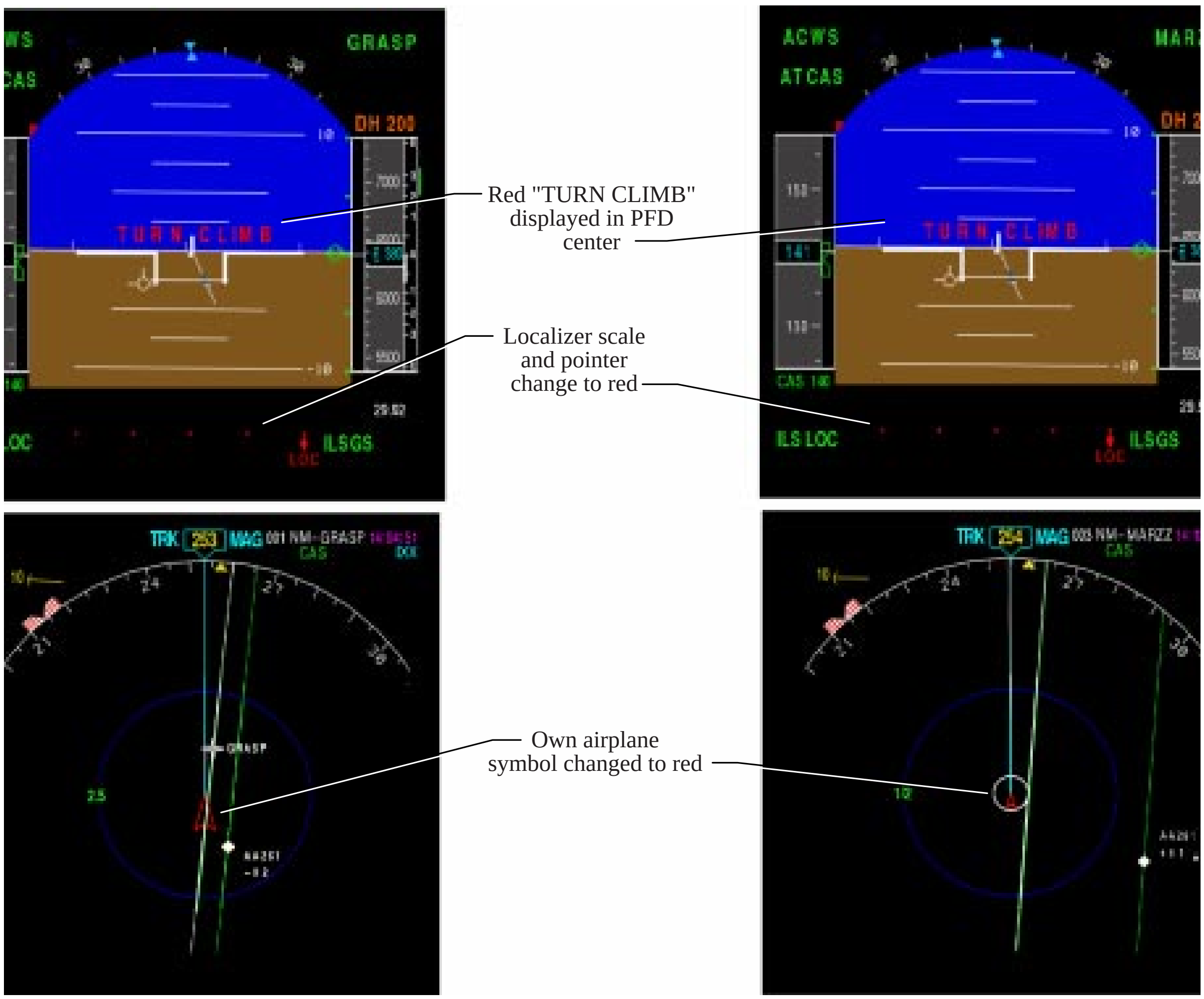
Figure 10. Nominal AILS displays, no alerts.



(a) Modified conventional display.

(b) Enhanced display.

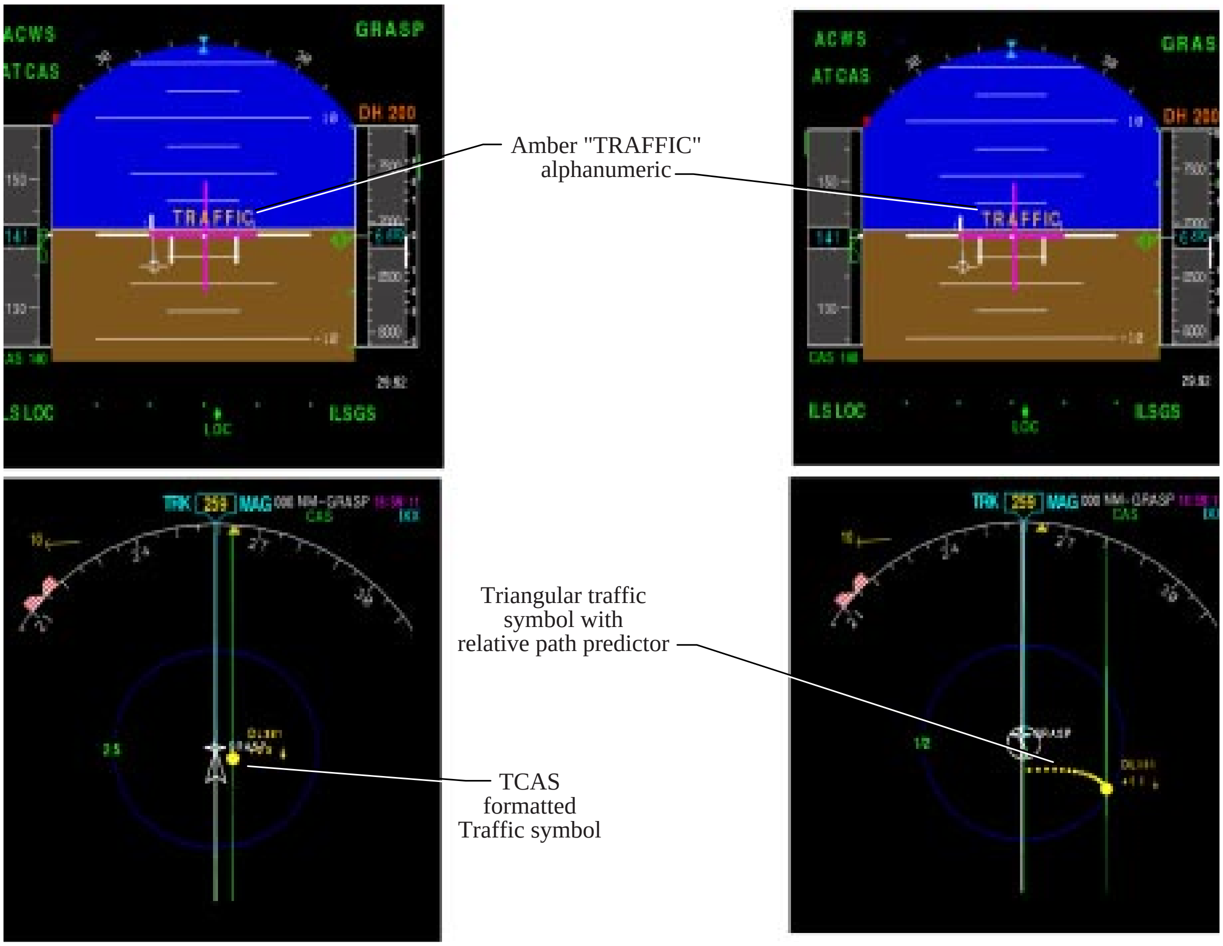
Figure 11. Level-two localizer deviation alert.



(a) Modified conventional display.

(b) Enhanced display.

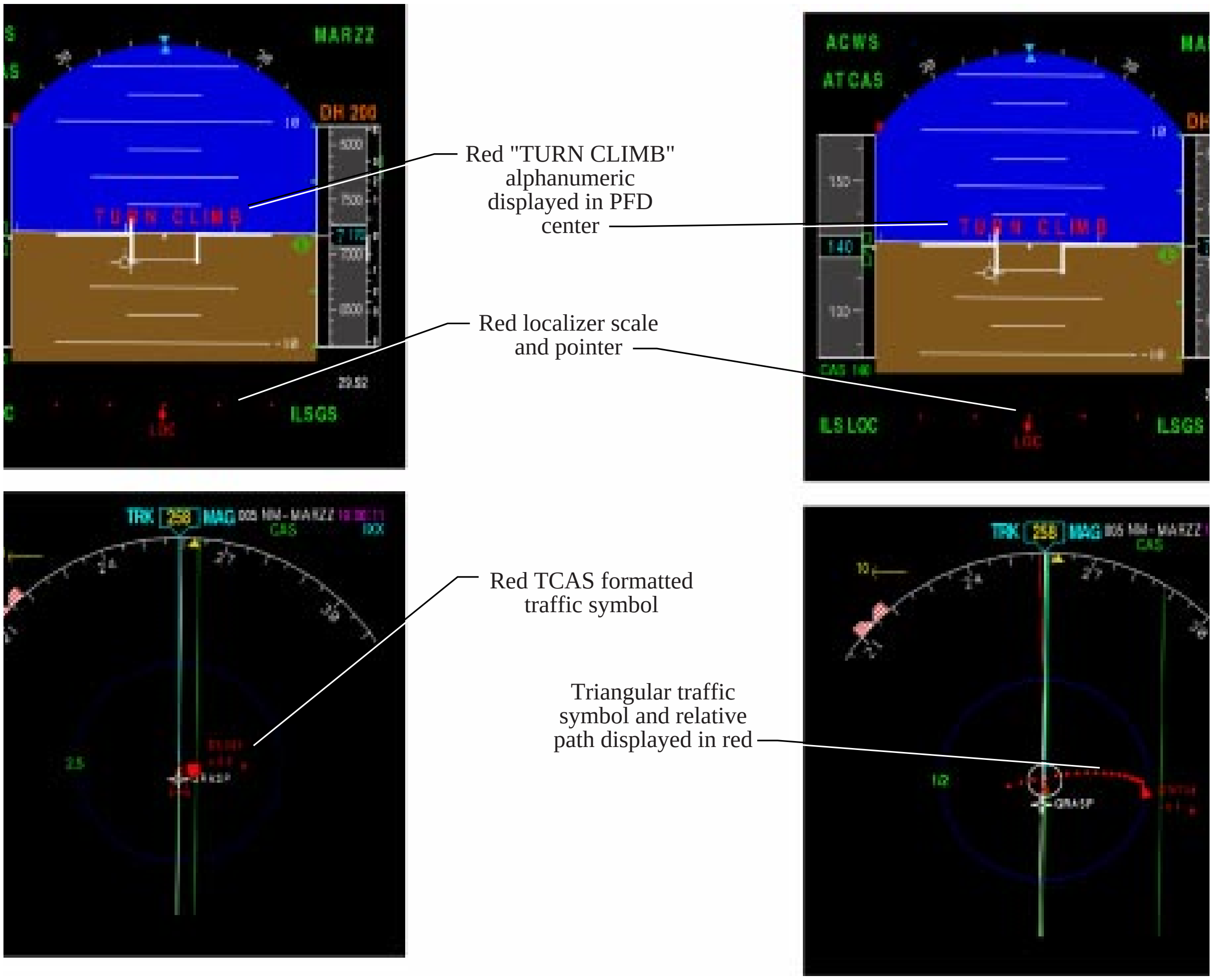
Figure 12. Level-three localizer deviation alert.



(a) Modified conventional display.

(b) Enhanced display.

Figure 13. Level-two traffic alert presented on the PFD and ND.



(a) Modified conventional display.

(b) Enhanced display.

Figure 14. Level-three traffic alert (mandatory break-off using the escape maneuver).

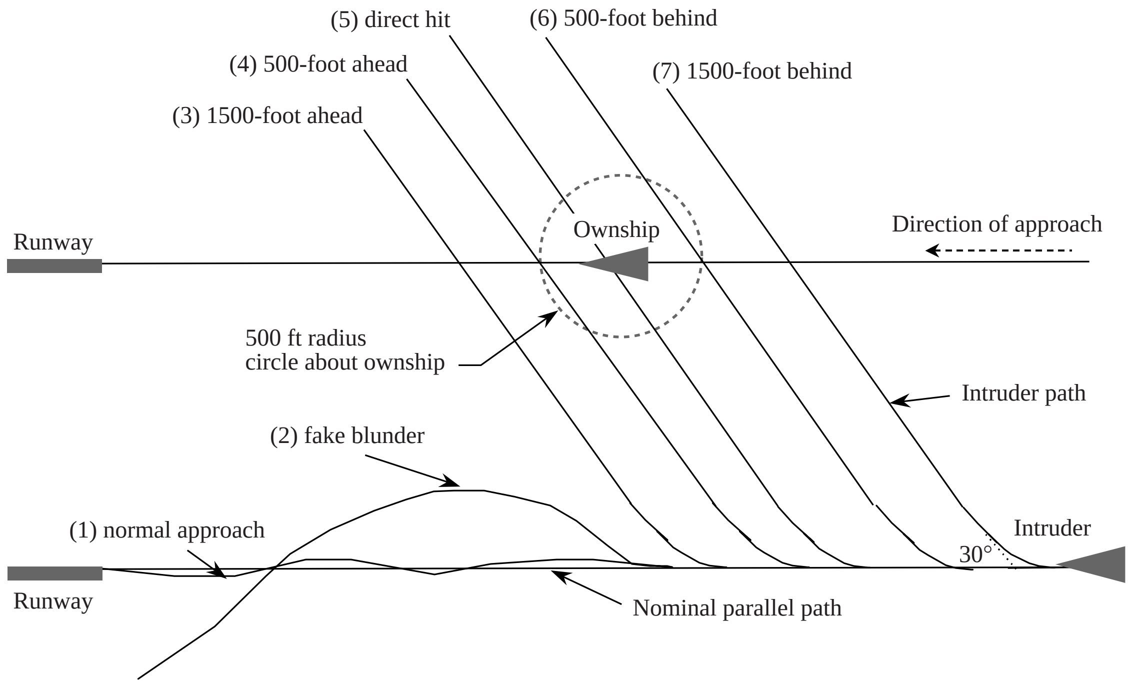


Figure 15. The seven traffic path geometries (TPG's) used in the tests.

Figure 16. TSRV Simulator.

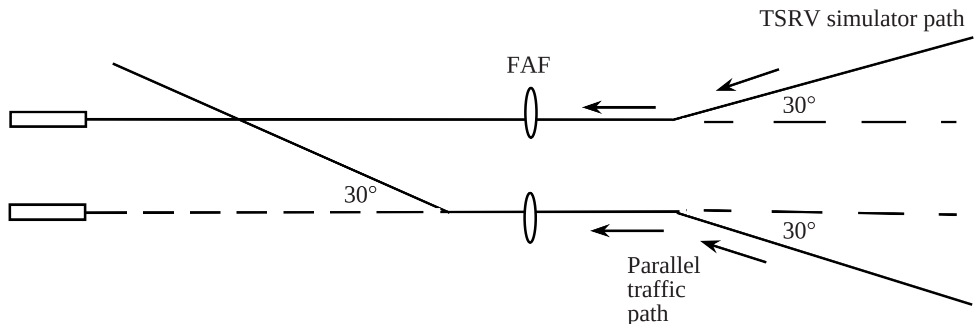


Figure 17. Intrusion geometry format.

	Count	Mean	Std	Max	Min
Mod. Conv.					
Average	192	1953	274	2395	1183
2500 ft	96	1921	293	2395	1183
3400 ft	96	1986	251	2355	1319
Enhanced					
Average	192	1939	258	2437	1242
2500 ft	96	1927	268	2437	1242
3400 ft	96	1950	248	2298	1276

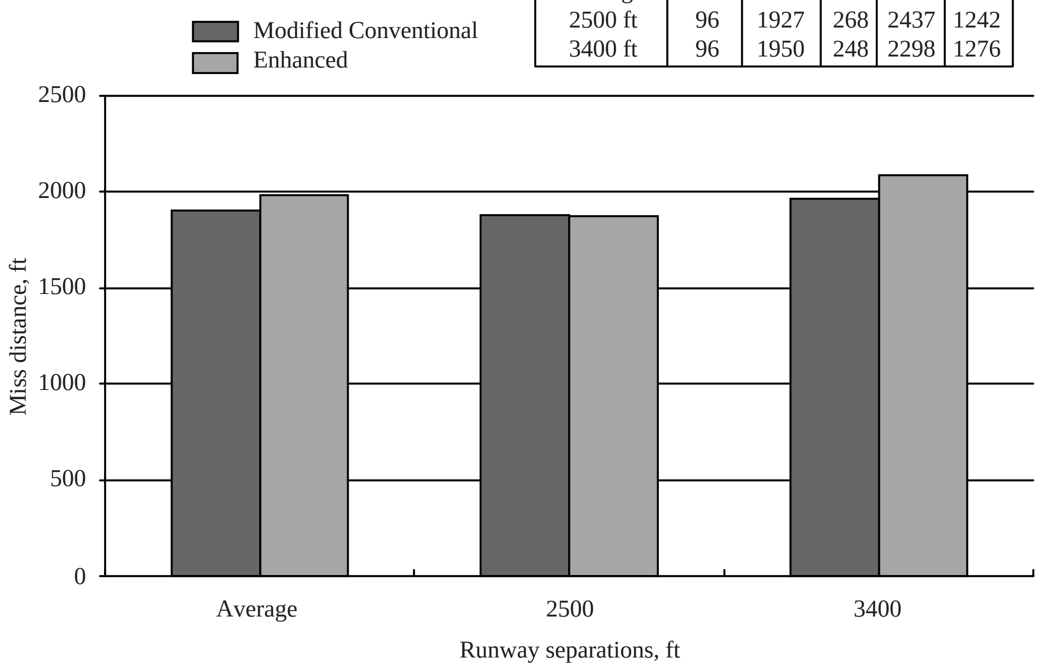


Figure 18. Miss distance versus runway spacing and display format.

Minimum Separation
From Time of Alert to End

	Count	Mean	Std	Max	Min
2500 ft					
Average	192	1924	280	2437	1183
SLOW	96	1869	364	2437	1183
FAST	96	1979	139	2310	1636
3400 ft					
Average	192	1968	250	2355	1276
SLOW	96	1874	298	2305	1276
FAST	96	2062	137	2355	1664

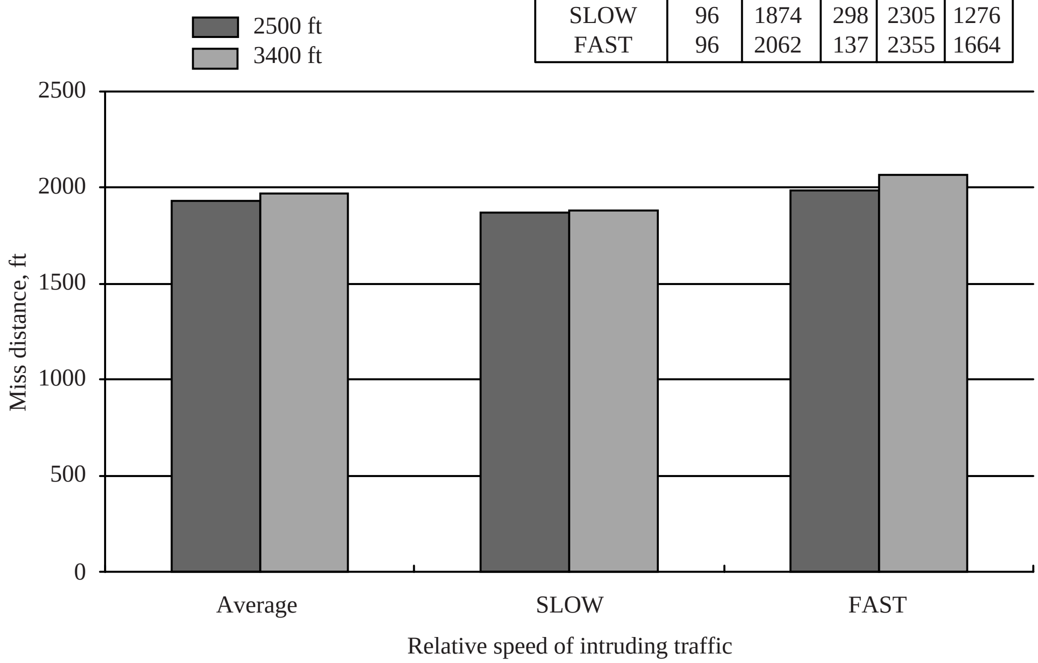


Figure 19. The effects of runway separation and relative speed on miss distance.

	Slow	Fast	Total
Mean	1871	2021	1946
Std	331	144	266
Max	2437	2355	2437
Min	1183	1636	1183
Count	192	192	384

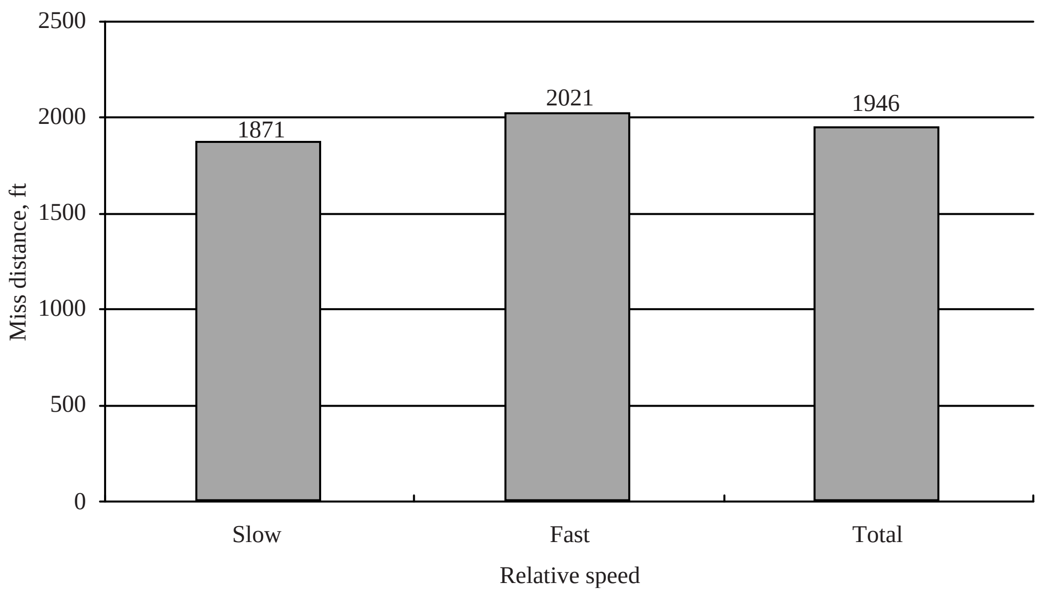


Figure 20. Mean miss distance versus intruder relative speed.

	Count	Mean	Std	Max	Min
Mod. Conv.					
Average	192	751	433	1611	129
Slow	96	1047	372	1611	418
Fast	96	455	247	916	129
Enhanced					
Average	192	756	439	1663	133
Slow	96	1049	390	1663	435
Fast	96	462	247	928	133

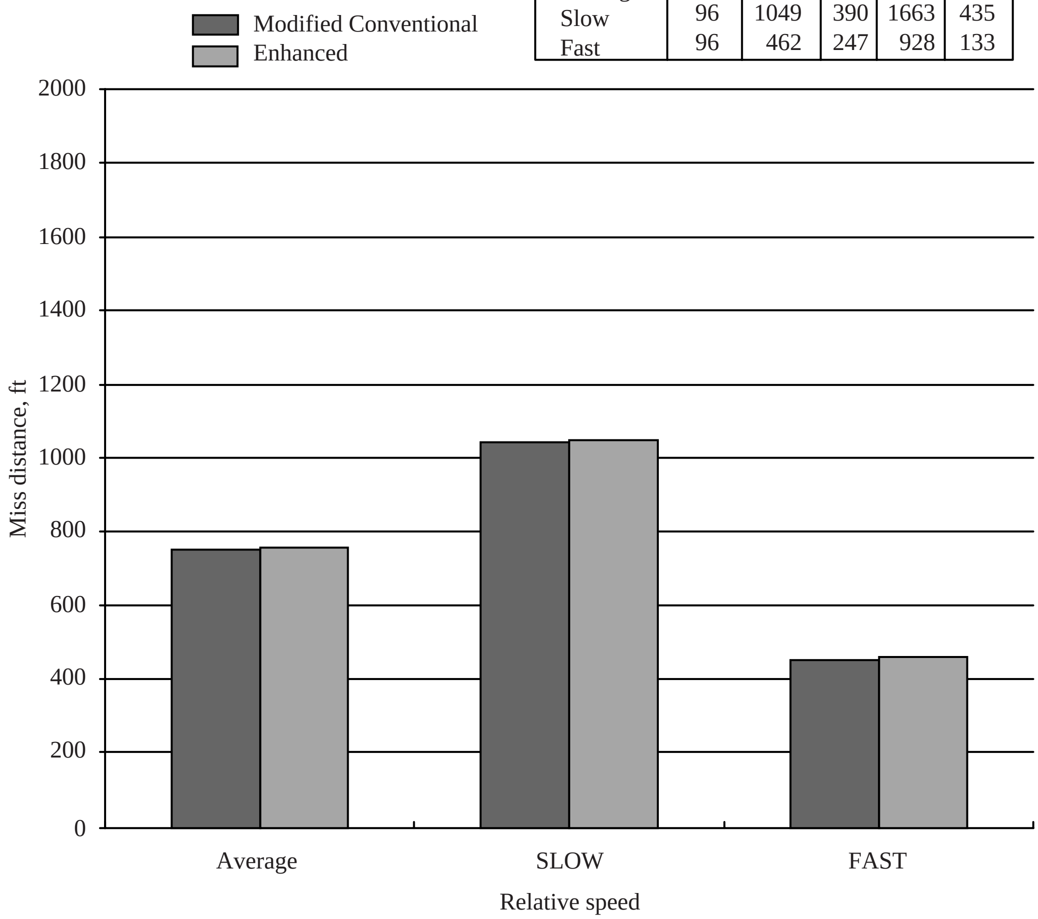


Figure 21. Lateral deviation of the intruder from its approach centerline at the time of alert.

	Direct hit	500 ft ahead	500 ft behind	Combined
Mean	2058	2032	1746	1946
Std	157	177	311	266
Max	2354	2437	2263	2437
Min	1564	1636	1183	1183
Count	128	128	128	384

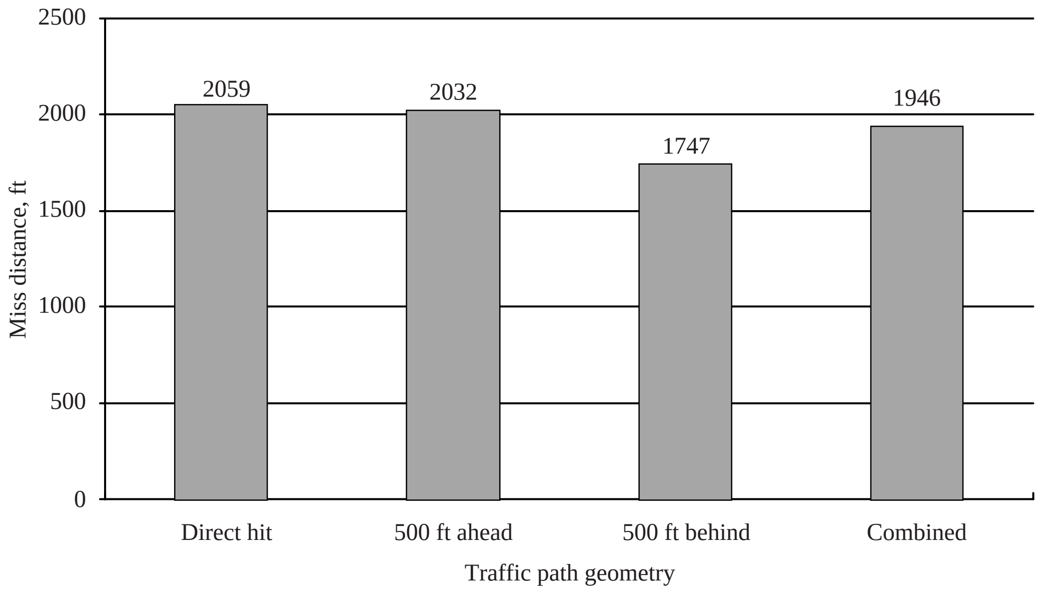


Figure 22. Miss distance versus the level-three-alert traffic path geometries.

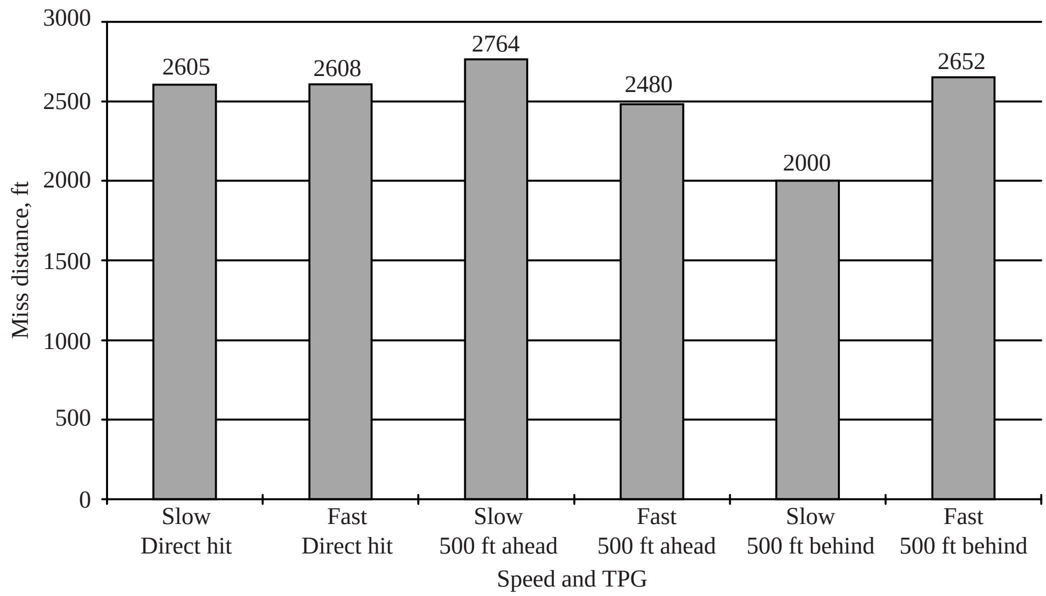


Figure 23. Separation distance between the two airplanes at the time of alert for traffic path geometries and speed combinations.

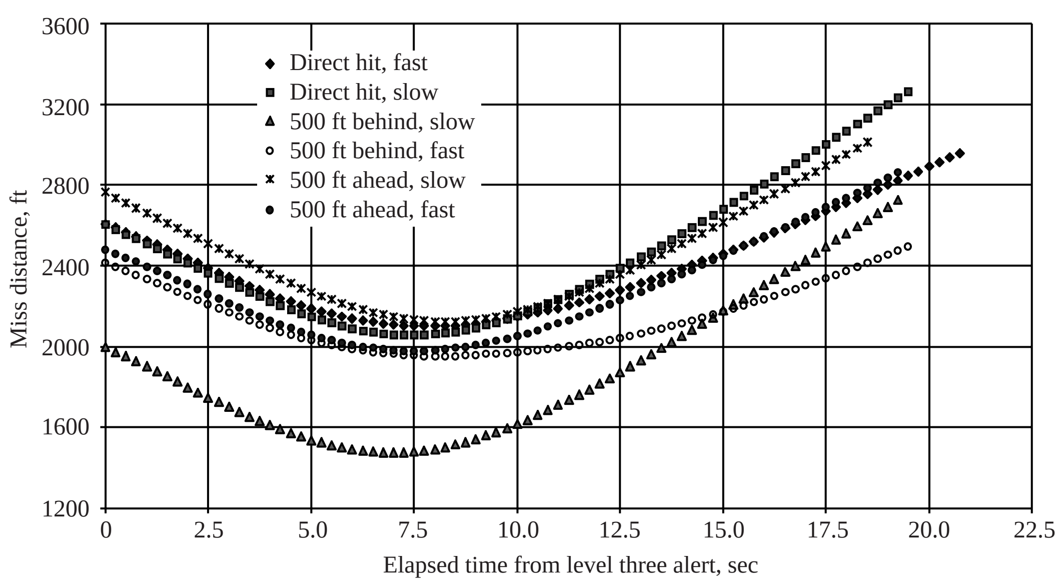


Figure 24. Separation of the two airplanes versus time.

	Count	Mean	Std	Max	Min
SLOW					
Average	192	1871	331	2437	1183
2500 ft	96	1869	364	2437	1183
3400 ft	96	1874	298	2305	1276
FAST					
Average	192	2021	144	2355	1636
2500 ft	96	1979	139	2310	1636
3400 ft	96	2062	137	2355	1664

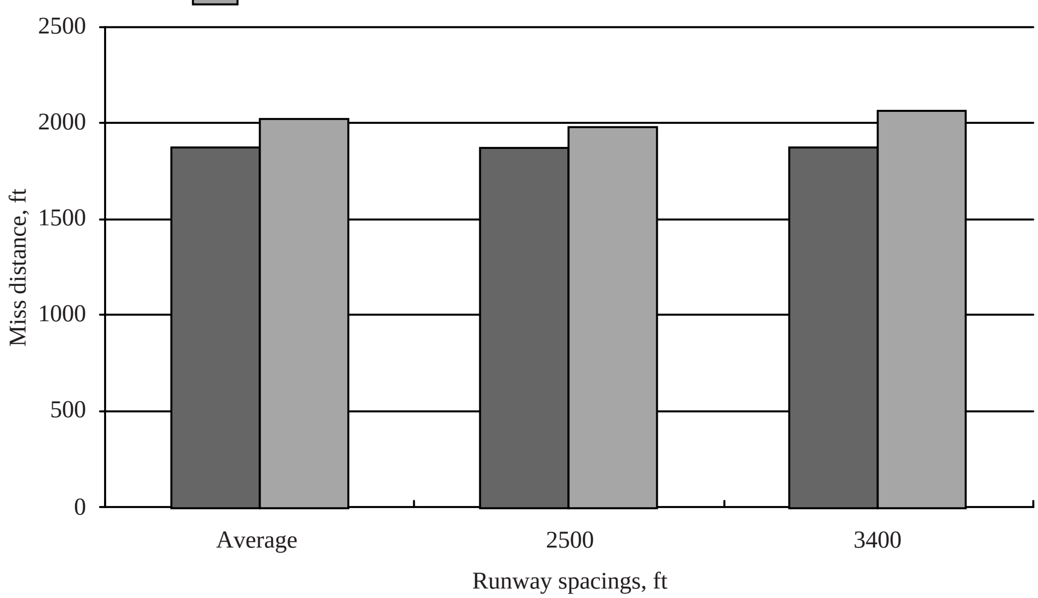


Figure 25. Effects of intruder relative speed and runway spacing on miss distance.

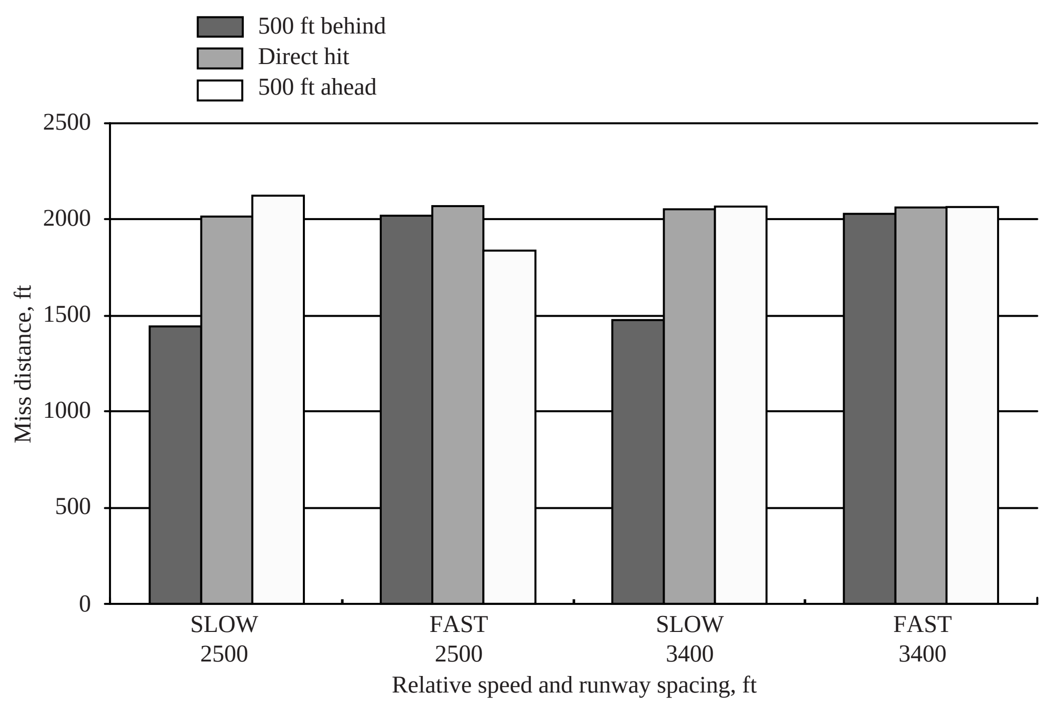


Figure 26. Miss distance as a function of intruder speed, runway spacing and traffic path geometry.

	Count	Mean	Std	Max	Min
Mod. Conv.					
Average	192	0.70	0.19	1.31	0.03
2500 ft	96	0.71	0.19	1.28	0.19
3400 ft	96	0.69	0.20	1.31	0.03
Enhanced					
Average	192	0.73	0.25	1.78	0.03
2500 ft	96	0.73	0.25	1.44	0.41
3400 ft	96	0.72	0.28	1.78	0.03

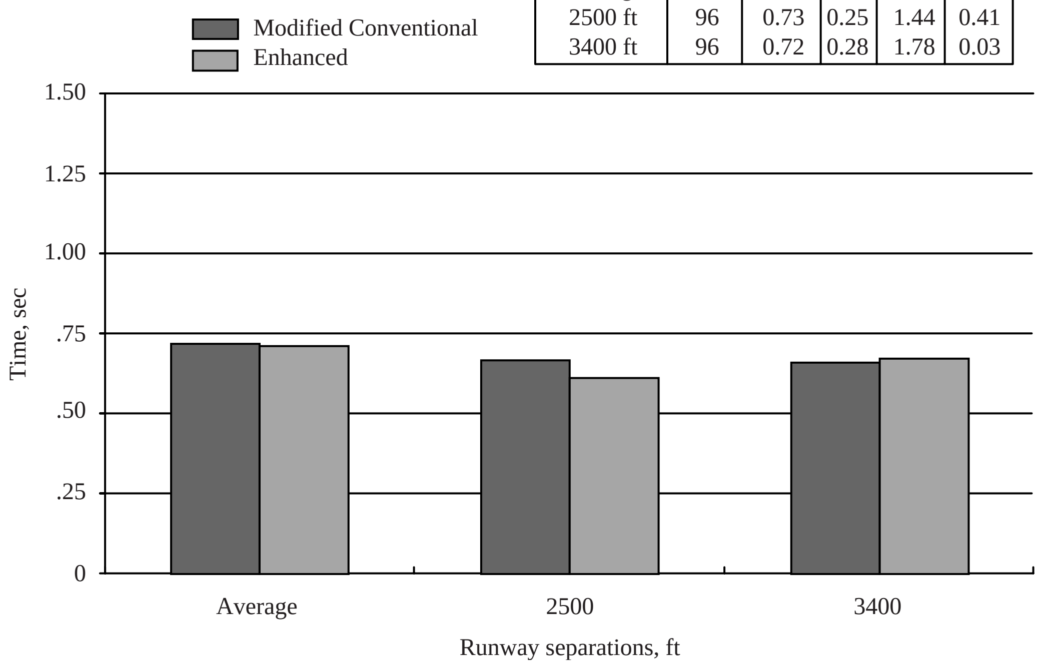


Figure 27. Pilot reaction time versus display format.

Figure 28. The TSRV Simulator with oculometer data areas illustrated by white dashed lines.

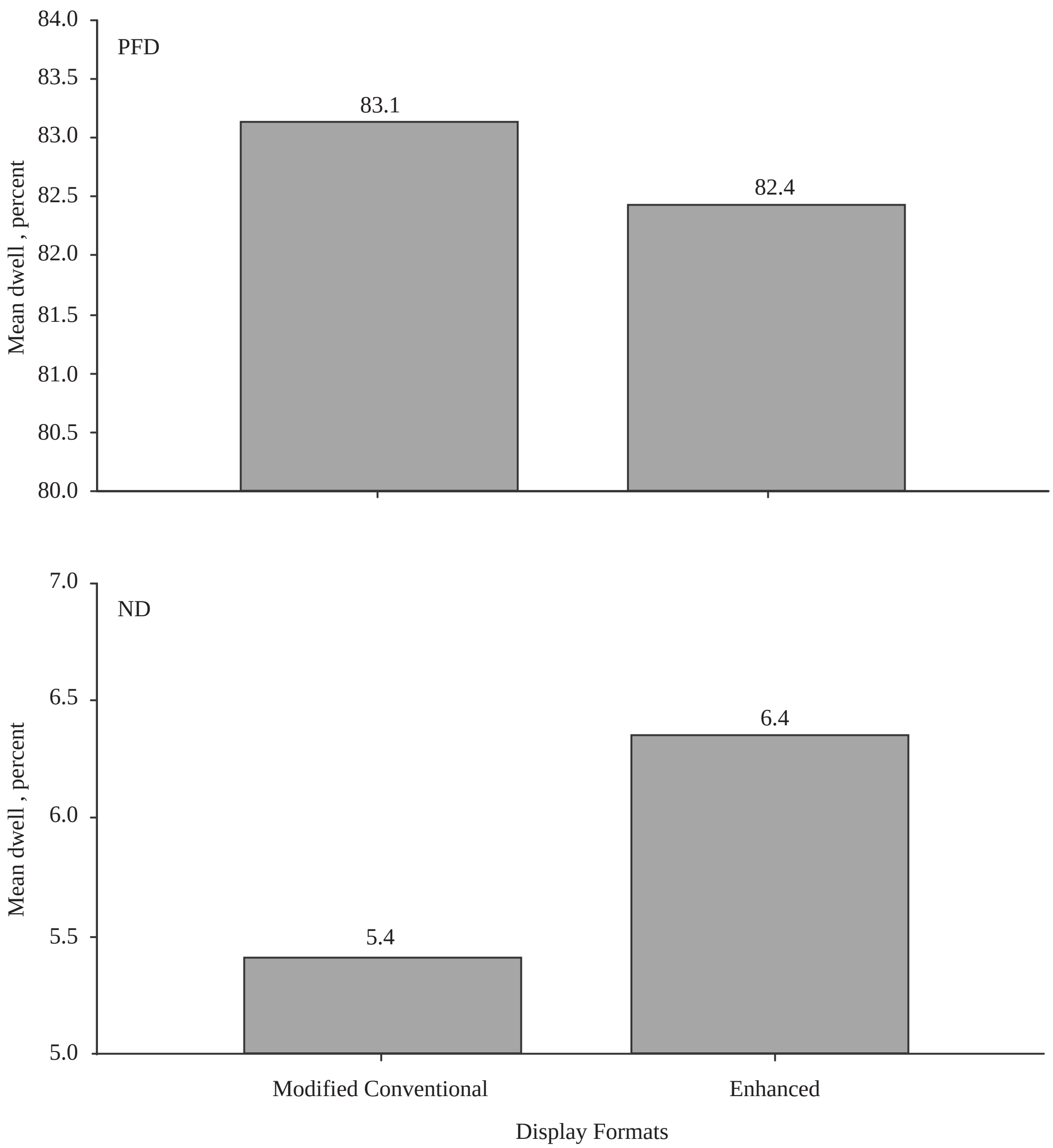


Figure 29. Dwell percentages on the PFD and ND for the two display formats, all runs with intrusions.

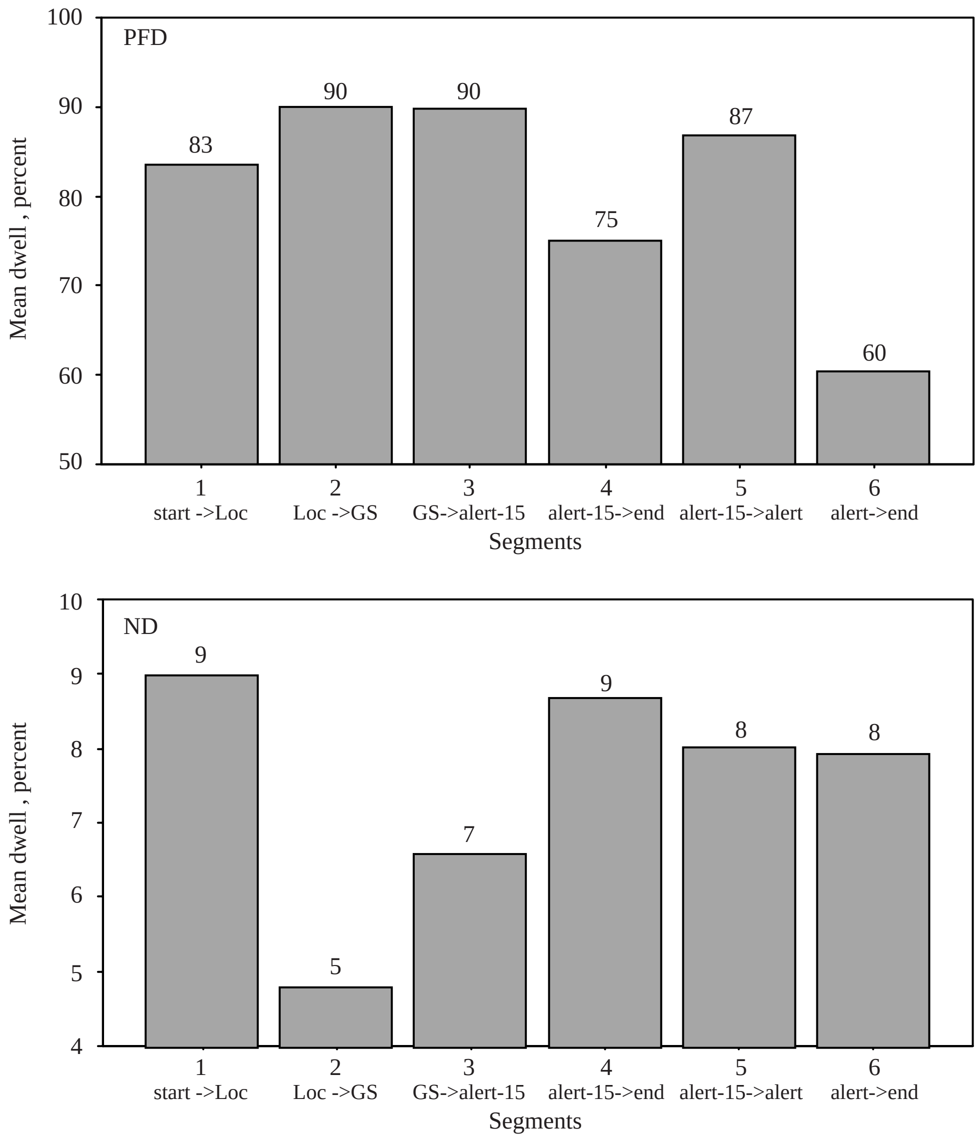


Figure 30. Dwell percentages on the PFD and ND by run segment (display formats combined).

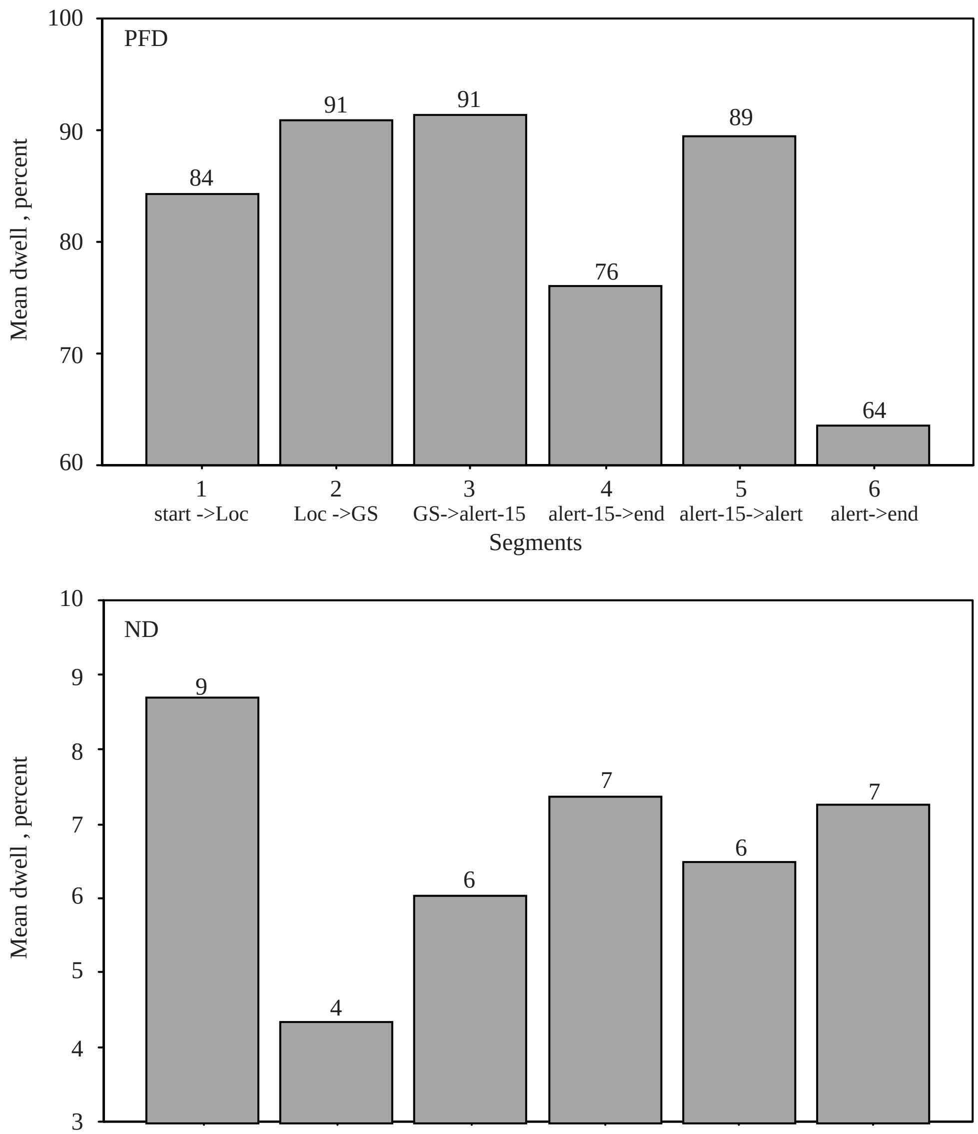


Figure 31. Dwell percentages on the PFD and ND by segment, modified conventional display.

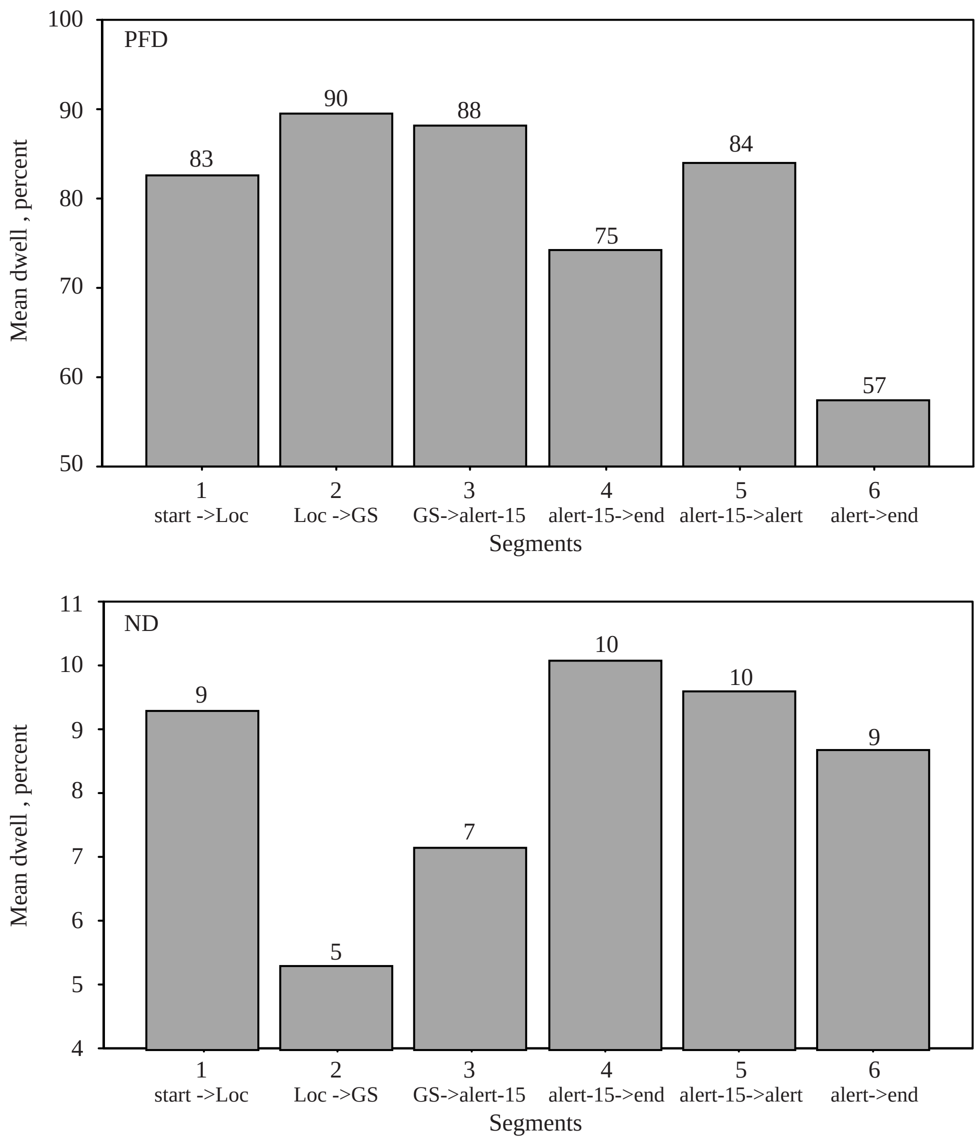


Figure 32. Dwell percentages on the PFD and ND by segment, enhanced display.

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13. ABSTRACT *(Maximum 200 words)*
A number of our nation’s airports depend on closely spaced parallel runway operations to handle their normal traffic throughput when weather conditions are favorable. For safety these operations are curtailed in Instrument Meteorological Conditions (IMC) when the ceiling or visibility deteriorates and operations in many cases are limited to the equivalent of a single runway. Where parallel runway spacing is less than 2500 feet, capacity loss in IMC is on the order of 50 percent for these runways. Clearly, these capacity losses result in landing delays, inconveniences to the public, increased operational cost to the airlines, and general interruption of commerce.

This document presents a description and the results of a fixed-base simulation study to evaluate an initial concept that includes a set of procedures for conducting safe flight in closely spaced parallel runway operations in IMC. Consideration of flight-deck information technology and displays to support the procedures is also included in the discussions. The procedures and supporting technology rely heavily on airborne capabilities operating in conjunction with the air traffic control system.

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